THE TORQUE HOSE ACTUATOR:

A STUDY OF THE DEVELOPMENT OF A NEW PRODUCT

A Thesis Submitted for the Degree

of Doctor of Philosophy

by

Mark Haydn Oakley

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SUMMARY

THE TORQUE HOSE ACTUATOR: A STUDY OF THE DEVELOPMENT OF A NEW PRODUCT

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This thesis presents the results of a multidisciplinary study of the development of a new product. The project, which was industrially based, started from the conviction that a new technical concept - the Torque Hose- could be converted into a worthwhile product. It was recognised that a number of engineering problems would have to be solved before success could be achieved. The thesis reports this technical work which included an experimental investigation into the fatigue life of reinforced rubber hoses. The results of this investigation produced new data of general relevance in rubber engineering.

Market analysis work, which was undertaken to assess the commercial prospects of the new product, helped determine the structure of the project within the normal business activity of the firm. During the course of the project work, the organization of the firm underwent substantial change, particularly with respect to product development work. This gave the opportunity for alternative forms of innovative organization to be analysed as each was applied. From this, a number of conclusions were drawn about product innovation in industrial companies.

Thus, the thesis presents analyses of the technical, marketing and organizational problems of new product development. It is intended that is should be read also as a detailed case study of a new product exercise.

Key Words: Innovation; product development; rubber engineering.

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M.H.O.

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CHAPTER 1

INTRODUCTION TO THE STUDY

Fig 1.1 Torque Hose Project - A Presentation to the Project Supervisors

1.1 The Concept of the Project

The project which is described in this thesis was set up jointly by the Interdisciplinary Higher Degrees Scheme (IHD) of Aston University and the Engineering Group Division of Dunlop Ltd. Within IHD, the project was part of a 'Total Technology' course, with a programme of lectures and assignments to complement the research work. The practical work was based at the Engineering Group site at Coventry and occupied 2½ years; during this time the writer worked as an employee of the company.

As an industrial project, all work was directed to the achievment of solutions to problems of importance to the company - a basic concept of the IHD scheme. Thus, the research was not structured or conducted in its entirety in a manner associated with traditional academic research. The direction and shape of the project were fixed mainly by the needs of the company, although the various stages of work were carried out with as much academic rigour as possible. Since the project was a part of the general business activity of the company, its structure was dynamic - it was redesigned several times to meet the needs of changing circumstances. In this way the project has successfully produced the results expected of it by the company and by IHD.

The object of the project was the development of a new product - a pneumatic actuator - the basis of which was a recently discovered phenomenon of a certain type of reinforced rubber hose. In Dunlop, this special hose was referred to as 'Torque Hose' and the project was designated the Torque Hose Project. The hypothesis upon which the project was founded was that the concept of the Torque Hose could be developed and incorporated in a new product. Further, that the new product would have advantages over similar devices already on sale and would therefore enable Dunlop to diversify into new areas of business. It was recognised that a number of technical and marketing problems needed to be investigated, and during the course of the work, it was found that organizational problems were also highly important.

1.2 Interests and Requirements of Participants

It has been noted that this project was a joint venture between the University and Industry. A consequence of this was that a number of diverse interests had to be satisfied simultaneously. The academic supervisors required that the work should be carried out in a scholarly manner and that the results would be presented in a satisfactory way to the University.

In Dunlop, several parties had an influence on the project. The Training Department, which partly funded the study, viewed the IHD scheme as a component of the company's management development programme (1), building up the skills, knowledge and experience of the employee-student. The Product Development Director who supervised the work in Engineering Group expected the project to be tackled in an efficient manner, alongside the other development projects in his department, without excessive introspection or diversion. Also other senior managers were interested in the project. At one stage, the project became the centre of a management experiment in organization and received much attention. In contrast, there were times when prospects were considered so bad that termination seemed inevitable.

IHD maintained a balance between the academic and industrial elements on the project. It also represented the interests of the Science Research Council which provided financial support.

The student had a set of objectives too. These included the wish to develop an ability to organize effective research and to understand the problems involved with innovation and industrial management.

These conflicts were not incompatible, as the completion of the work and this thesis demonstrates. But they were real constraints as will be apparent in the text - there were times when the student felt some envy of colleagues working within a more traditional framework of study.

1.3 External Economic Considerations

The writer started work on the project in the autumn of 1975. At that time, and during the whole course of the project, national and international economic depression was a cause for the greatest concern. The effects in the U.K. were acute. Unsatisfactory levels of unemployment and inflation of wages and prices were causing widespread hardship and demoralisation. Even more worrying for the long term prosperity of the country was an apparent inability to organize effectively for the innovation and manufacture of the goods necessary to generate adequate wealth to provide a satisfactory standard of living. In a single edition of an engineering periodical (2) it was stated that

- For the first time, U.K. car manufacturers had achieved less than 50% of the total sales to the home market - a psychologically important statistic. Virtually all private purchases were of foreign cars and the number of business purchases of British vehicles had decreased as well.
- Japanese imports of bearings were becoming so successful that a 20% increase in their price was being demanded to protect U.K. manufacturers.
- In the face of cheap imports, British cutlery manufacturers had retreated so far

that they operated only in a small market at the top of the price range.

Often, it was argued that foreign competitors were using unfair methods, were 'dumping' products or were exploiting their labour. But while many British companies were apparently resigning themselves to stagnation and decline, there was some realization, evident for example in economic reports, serious TV and radio programmes, management journals and political statements, that, whatever the cause of the problem, the key to growth was effective technological innovation.

In consideration of these broader influences, it was felt that an insulated, narrow execution of the research project, in the form in which it had been presented originally, would be unsatisfactory. It was of vital importance to understand more about how innovation should be managed for success and it was decided that a wider evaluation of the Torque Hose project could reveal valuable information. Consequently, although the project was defined intially in terms of (i) technical development to solve a number of stated problems and (ii) market research to evaluate the potential of the device (3), the scope widened to include consideration of the organizational philosophy of new product development using the original subject as a point of reference.

The approach to the study was determined mainly by the factors already discussed. However, certain other influences did have an effect and it is appropriate that these should be mentioned at this stage.

Fellow employees, and acquaintances in other companies, provided a stimulus in the attempt to understand how companies organize for innovation. The writer noted that in situations of both success and decline, most employees - even those who were quite senior or highly qualified - showed little interest in the organizations of which they were a part and accepted passively the limits associated with their roles. At the same time, many of these employees expressed frustration and dissatisfaction but lacked the confidence or motivation to analyse their own companies and to seek to cause beneficial changes to occur.

Similarly, some university contacts and others who operated outside industry, often seemed to have idealized impressions of how work was organized in companies. The desire to modify these impressions by providing factual information was an incentive to persevere with the study.

1.4 Definition of the Aims of the Study

Having discussed the factors which determined what direction this project should take, the aims of the project must now be stated. In detail these were:

1. To carry out the engineering development work necessary to turn the concept of the Torque Hose into a saleable product.

This included determining what information already existed and what further data was required. Design work was required, both of solutions to problems and of equipment for experimental work.

2. To carry out the research work necessary to assess the market potential of the new product. To provide business information, so that sound management decisions could be taken.
3. To analyse the organizational context in which the project was developing and to compare this with other forms of innovative organization.
4. To achieve an understanding of the conditions necessary for the successful development of new products. Although based on the research carried out in Dunlop, this should have general relevance.

The first three aims were concerned with the reporting of factual information and results of investigation. The final aim, on the other hand, implied judgement as well as observation and so it was a potential source of disagreement and criticism. It was decided that this risk was worth taking. Since so much of British Industry was faced with the problem of coping with rapid change caused by external events, it was felt that the study could make a valuable contribution to the knowledge of a dominant feature of that change - the organization of new product development. It is the writer's belief that effective change can be achieved only where an informed intellectual approach is used. This means that the drive for change must come from individuals or groups who are accustomed to using high levels of conceptual technique in the normal course of their work. Hence it is to senior executives in particular that this part of the thesis is addressed. It is hoped that the information presented, together with other studies published elsewhere, will assist in the formulation of strategies for successful innovation and growth.

1.5 Plan of the Thesis

The thesis contains six chapters in addition to this introductory first chapter. Also, a number of appendices have been included so that information can be provided which otherwise would tend to interrupt the flow of the main presentation. Photographs, drawings and charts have been used in the text where it was thought that they would assist clarity of explanation. In preparing the thesis, the main objective has been to present as much detail as possible whilst employing an economical style.

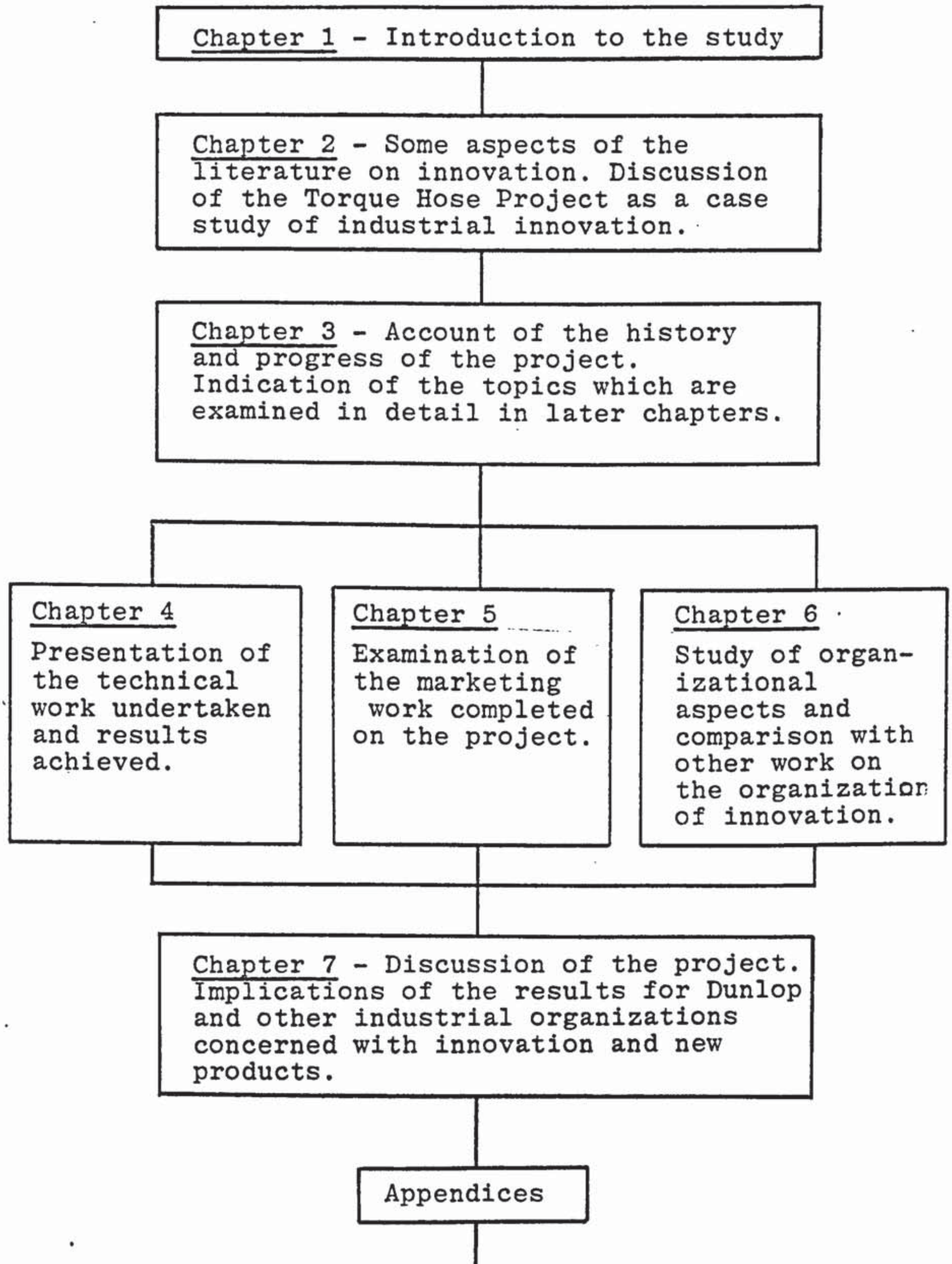
Fig.1.2 shows in diagrammatic form the construction of the thesis. The notion of the three 'parallel' chapters is to stress that the topics which they discuss are interdependent and interrelated.

In further detail, the contents of each of the chapters are:

Chapter 2: A resumé of the views of writers on innovation. Topics covered include the need for innovation, the problems of change, types of innovation and the role of management in innovation. The purpose of this chapter is to put into context the Torque Hose project as a case study of innovation. The ideas presented in this chapter also provide material for discussion later in the thesis.

Chapter 3: This chapter tells the story of the project from its inception to the present. It includes notes on the work done at Dunlop's Research Centre and at Engineering Group. Information is also given of the various organizational changes which affected the project. The chapter indicates those aspects

Fig. 1.2 Model of the Thesis



which are given greater examination in the following three chapters.

Chapter 4: Full information is given about the technical work involved in the project including details of experiments on the mechanical characteristics of the hose, design and testing of end fittings, design of test rigs and prototypes, theory of the hose performance with reference to other work, and research into hose construction for better fatigue life.

Chapter 5: Discussion of the marketing organization and philosophy in Engineering Group, market research into secondary sources, preparation for research into primary sources and marketing information from potential distributors.

Chapter 6: Details of the changes in organization applied to the project and the consequences of the different types of structures observed. Features and outcomes of an experimental organization applied to the project.Comparison with other models of organization for innovation.

Chapter 7: Assessment of the results and observations recorded in the earlier chapters. Discussion of the implications for Dunlop and Industry in general. Suggestions for the organization of future new product development projects.

CHAPTER 2

A REVIEW OF LITERATURE RELATING TO INDUSTRIAL INNOVATION AND ORGANIZATION

2.1 Introduction

Whilst tackling the technical and marketing work connected with the Torque Hose, the writer also considered some of the broader issues implicit in the project. As a case study of industrial innovation, the project contained features that could be compared with those of other studies. The reasons for the existence of the project were examined. Why did Dunlop - or any company - need to develop new products ? What effect did innovation have on the existing company structure ? How were the resulting changes perceieved within the organization ?

Other aspects of innovation were examined. What were the processes and types of innovation found in industry ? What should be the management role in innovation ? In both of these aspects, the Torque Hose project demonstrated particular approaches and results. How did these compare with those reported in studies of other industriad organizations ? Had management writers satisfactorily and consistently reported the factors leading to the success or failure of innovative projects ? The organization of which the Torque Hose was a part, was of a certain form. What other forms of structure, appropriate to the development of new products, were reported in the management literature ?

This chapter contains the results of a literature review undertaken to examine these questions and topics. It provides a context for the project and is a source of reference for discussion later in the thesis, in particular, in Chapters 6 and 7.

2.2 The Need for Innovation

In the broadest sense, innovation is to do with progress. It reduces in operational terms to the introduction and widespread use of new products, new processes, new ways of doing things and new forms of industrial and social organization. In our society, we measure this progress in terms of prosperity (4). For a company, prosperity depends on sustained adaptation ; for although an industrial society can prosper if composed of innovative and non-innovative members, few industrial companies can expect to survive unless innovative forces are dominant within them. There may be a limit to the process of adaptation by companies - "the go-ahead company of one generation ... can often become the laggard of the next ; and to a remarkable extent corporations behave like individuals, becoming middle-aged, corpulent and sometimes just dying from old-age" (5).

In contrast, Basil and Cook (6) present the analogy of the business organization as an eco-system like a forest, capable of producing and developing healthy sub-systems whilst allowing out-dated, inefficient parts to die. Perhaps, the important word is 'capable', for it seems that the real problem is not the ability of those who control industry to understand the nature of survival, but to come to grips with the mechanics of effecting the necessary changes. Trying to find the products and forms of organization that can sustain and create wealth, may be regarded as 'the problem of the Seventies'. However, a quarter of a century ago, an article in "The Times" newspaper (7) argued that Britain was "bad at application and begetting new products ... applied research must be diverted towards clearly defined practical objectives ..." To achieve improvements, an increase in the number of managers with engineering and scientific backgrounds was advocated - 25 years later, the low supply and quality of technical graduates is often cited as a major reason for poor industrial performance. e.g. Swann (8).

Each company will realize its need for innovation in a different way. In one case, it may be that the market for a traditional product has been sharply eroded by a competitor's innovation. In another, the limits to growth may have been reached with existing products and new business activities are required to ensure continued prosperity. It has been said that there are 3 facts of modern life that every company has to know and reckon with (9).

1. The acceleration of change.
2. The growing similarity of competing products.
3. The growing sophistication of the consumer.

If these facts are ignored, then change, which may be fundamental in nature, may well feature as part of a crisis - the worst possible conditions for successful innovation. In their study of established firms entering new fields, Burns and Stalker (10) show that in every case, the primary factor in the firms' decisions to explore new technical ground in attempts to devise new products, was the shrinkage or loss of the markets for their traditional products.

However, even when a real attempt is made to change ahead of an anticipated crisis, expectations may not be achieved. Basil and Cook (11) refer to this as the "Strategic Gap" problem - the shortfall between the actions of organizations and the objective of orderly change. Six major causes of strategic gaps are given :

1. Environmental scanning deficiencies. In all cases, it is essential that detailed technical and marketing plans for new products are prepared. Frequently a social analysis of the effects and consequences of products is also necessary. For example, the creation of pollutants (by production effluent or by the product itself) or the exposure of employees and customers to risks, are factors which can seriously affect the success, profitability and image of a company.

2. Organizational inflexibility. After deciding to enter a new field, many firms find that success eludes them because of the attitudes and limited abilities of their employees.

3. Insufficient public support. Lack of

consistent government support is a common problem in some industries such as aviation and construction.

4. Resource inapplicability. A major example was the over-commitment by Rolls Royce to the RB 211 engine which resulted in bankruptcy for the company. Less dramatic are the companies who spend money on prestige research departments of doubtful productivity but fail to support relatively inexpensive innovative projects, because they are thought to be 'risky'.

5. Over-simplification stemming from inappropriate correlation of cause and effect. For example, loss of sales may not be caused entirely by product obsolescence - poor delivery, inadequate quality control, badly trained employees are just a few of the other factors that may be involved.

6. Ignoring change signals. Inexpensive electronic devices, for example, have replaced many mechanical components and the trend is continuing. Companies which fail to recognize these types of change - which may be quite rapid - are likely to lose most of their sales, unless their products also change.

2.3 Concepts of Change

Frequently it seems, organizations initiate change only when survival is seen to be at stake. In the normal course of events, preoccupation with current production leaves little scope for any real innovative change. As Schon points out, many firms demonstrate this attitude by paying lip-service to their product development activities. Whilst proclaiming official doctrines of innovation, such firms may, for example, encourage new product ideas, only to find consistently that none of them meets the stringent criteria laid down in advance. Similarly, many firms effectively eliminate change by oscillating between support and resistance - an 'on-again, off-again' approach to innovation. (12)

Not infrequently, a myopic concentration on the manufacture of existing products means that new products are never successfully developed. Griener (13) is critical of this attitude to new materials and products. He notes that successful change does not begin until strong environmental and internal pressures "shake the power structure at its very foundation. Until the ground under top managers begins to shift, it seems unlikely that they will be sufficiently aroused to see the need for change ...."

According to Twiss (14), resistance to change is a feature of older companies rather than younger ones. He has found that as companies reach maturity, strategies become more defensive and few innovations lead to new products which depart substantially from current practice. The reason often lies with the 'Chief Technologist' who is normally found to be the creative force in the young company but is less effective as the company evolves and a management team is built up around him. This means that in the mature company it becomes necessary to design some formal approach in order to cope with change.

An American study by Lynton (15) has examined large and small organizations and found that each may face circumstances in which they can no longer deal with change by intuitive means. It may be thought that an organizations's size is the primary factor in handling change. But Lynton has found that a decision to formally cope with change is not so much related to the size of the organization, as to the degrees of uncertainty in technology, markets and the environment. The necessary redesign of the organization into one which can accommodate higher degrees of uncertainty is invariably more difficult in older companies but is not markedly so in larger companies as compared with smaller ones.

Technological innovations always involve some change and for this reason they may be resisted (16). After all, the modern company is modelled on the production process which is (usually) rational and standardized, but innovation is not always rational and can be disruptive to those affected by it. More comprehensively, Bright (17) gives 12 reasons (Fig. 2.1) why the establishment may resist a technological innovation.

Fig. 2.1 Reasons for Resisting a Technological Innovation

(From J.R. Bright 'Research Development and Technological Innovation' Irwin 1964)

Not only is change important, but so is the rate of change in a company. A firm has to change at a sufficient rate and in an ordered manner to meet the conditions imposed from outside. A rate which is too high leads to chaos ; one which is too low may end in bankruptcy. And, in order to achieve the goal of prosperity, each subsequent change must be done a little better, a little more profitably, than the preceding one (18).

2.4 Processes and Types of Innovation

Later in this chapter (section 2.7), specific models of organization for innovation will be discussed. Before reaching that point, it is useful to look at what makes up the process of innovation, in order to understand the features which the organization must take into account.

Craver (19) refers to innovation in terms of 'industrial commercial development'. He says that this performs two functions :

1. Brings a market need to the attention of the research function.

2. Transfers the products of research out into the market.

According to Craver, the first step in an industrial commercial development is a market research study to either identify potential markets for new products or to define a need for which a new product could be developed. The second step is market development to introduce a new product to an existing market or an existing product to a new market.

From a different angle, Mueller (20) describes the "major ingredients of the innovative brew" as intellectual, technological and financial resources married with a given market. He observes that innovation is not an idiosyncratic accident. Meyers and Marquis (21) refer to three distinct types of technological innovation :

1. Complex systems such as communications networks and weapon systems. These involve long range planning and success usually depends on the skill of men who sort out the good from the bad approaches on a large scale. This is not a common type of innovation in most firms.

2. Radical breakthroughs in technology that change the character of an industry. For example, the jet engine, stereophonic sound and xerography. These innovations are rare and unpredictable and are predominantly the product of independent inventors or of research by firms outside the industry. *

3. "Nuts and bolts innovation" - essential for the average firm's survival. It must be done because competitors do it. This is the category into which the Torque Hose falls if the device is considered as an extension of existing rubber hose technology. From the point of view of the hose as the basis of a new pneumatic control product, the device falls into the previous category - in this case Dunlop being the firm outside the industry.

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* As Freeman (22) points out, this does not mean that the skills of the large firms are not required. He shows that in a majority of cases, breakthroughs produced by independent inventors owed their subsequent successful commercial introduction to the development work and innovative efforts of large firms.

According to Meyers and Marquis, for successful "nuts and bolts" innovation, five steps are required :

1. Recognition of both technical feasibility and demand

2. Idea formulation resulting in a design concept.

3. Problem solving - of unanticipated problems.

4. Development - resolution of problems of market uncertainty and scale-up.

5. Utilization and diffusion of new products in the market.

Similarly Twiss (23) describes technological innovation as a conversion process, since industry is generally seen as a process which converts raw materials into products. Thus innovation may be product oriented (Fig. 2.2), predominant when the consumer was weak,

Fig. 2.2 Technological Innovation as a Conversion Process - Product Orientation

(From B.C. Twiss 'Managing Technological Innovation' Longmans 1974) but since the 1950's the 'marketing concept' - associated with both domestic and industrial consumers - has grown as a result of a change of emphasis. This process usually prevents the initiator or technologist from direct contact with the user so the alternative approach (Fig. 2.3) is preferable. Here scientific or technological knowledge is converted directly and efficiently into the satisfaction of a customer need.

Fig. 2.3 Technological Innovation as a Conversion Process - Technology/ Market Orientation

(From B.C. Twiss 'Managing Technological Innovation' Longman 1974)

2.5 The Management Role in Innovation

Even in this period of economic difficulty, it is clear that change is still taking place and that the rate of change is still increasing (24). The electronic calculator revolution has had rapid effects on business and education and is an indication of many other fundamental changes caused by electronics. The trend to higher unemployment* in Western countries is a consequence partly of the production innovations which are occurring in many industries. In every direction, changes are continually occurring - from new methods of manufacturing consumer goods to new ways of recording and communicating information (25). Equally clear is the fact that more goods are being produced by newly developing industrial countries making competition for markets ever more intense.

Hence, it is not an overstatement to say that the major management challenge of our time is to ensure planned and orderly change. In many cases, the survival of the organization will be at stake. It is disturbing that few organizations seem prepared for this challenge. (27). Many are engulfed in systems which perpetuate conformity, precedent and procedure and, as already noted, reaction to crisis continues to be the primary

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* It may be argued that technological innovation promotes other social changes such as increasing personal mobility and divorce rates in the West and widespread poverty and malnutrition in under-developed countries (26)

model of adjusting to change (13). At the time of writing, British Leyland and British Steel are painful examples.

The problem is huge (and in its entirety is outside the scope of this discussion) involving issues of government policies, attitudes and activities of trade unions, division of wealth and power, and resources of energy and materials. However, one major factor is the style of management which is practised and encouraged in industrial organizations. Of particular importance is the ability of individual managers to initiate, and be responsive to, change. Basil and Cook (28) have drawn up a comparison (Fig. 2.4) of the features of 'traditional' and 'change responsive' managers.

A similar categorization of styles is that of 'Mechanistic and Organic' forms of management, as described by Burns and Stalker (29). They found that mechanistic systems are appropriate to stable conditions, are hierarchical and are found where problems are likely to be predictable. Organic systems are appropriate to changing conditions, tend to dispense with organization charts and 'shape' themselves to the problem being tackled. It is important to realize that there are stages between the two forms, indeed the system which is suitable for one project is not likely to be so for another.

Mechanistic systems tend to be inhibiting to the

<u>Fig. 2.4   The Managerial Role in Transition</u>
(from D.C. Basil and C.W. Cook
'The Management of Change'
McGraw-Hill   1974)

generation and flowering of new ideas except at the top where there is knowledge of the total situation. Such systems are seldom able to accommodate product development departments; similarly development departments which have a mechanistic system imposed on them are unlikely to be successful new product generators. Mechanistic organizations become less adaptive as the following characteristics evolve within them :

1. Increase in the number of levels of supervision.

2. Control by detailed inspection of work methods rather than by evaluation of results.

3. Communication consisting of instructions and decisions rather than exchange of advice, consultation or information.

4. Confrontation of win-lose nature rather than collaboration.

5. Low ratio of managers and professionals to employees who are performing mainly physical, low complexity tasks.

6. Insular attitude of top management with sense of commitment to past decisions.

7. Self-selection of management incumbents with management in-breeding through highly restrictive internal promotion system.

In contrast, Whitfield (30) describes the characteristics which are commonly found in those organically-structured groups which have been successful at innovation. These characteristics include :

1. All members make a full contribution ; co-operation is accepted as the way of achieving the best result.

2. Short term leadership tends to rotate according to the immediate needs of the job.

3. Decisions are made by the people who are best informed on the subject. These are not necessarily the most senior present.

Organic systems are often disruptive because people are preoccupied with not knowing the limits of their responsibilities ; to balance this, there is usually a general awareness of the common purpose of the organization. For some, e.g., Bennis (31), the total absence of structure is seen as the ideal organic form but the present writer has found no reports of success from such idealised systems.

The problem for management is one of very careful judgement in designing the correct system of operation. "All organizations exhibit simultaneous demands for routinization and for innovation. The balance of these countervailing pressures determines the organization's climate for the creative member" (32).

Finally in this section, mention must be made of the importance of the role of the Chief Executive Officer. Many writers acknowledge that a key to the innovation process is the Chief Executive's role in understanding the innovation ethic and in making a commitment toward innovation. For example, Pelz (33) stresses the importance of high quality leadership when he says that performance is good when people have a sense of being headed by a competent chief. Unless a very strong direction comes from the top of an organization, the forces of inertia at middle levels will ensure that only pedestrian performance, at best, will result. The main problem for an innovative group within a company is getting sufficient power to survice. It is up to the Chief Executive to delegate to it the necessary power and resources. The innovative effort must be seen as a vital requirement for meeting long term objectives.

An essential part of the senior manager's job, then, is to provide for the innovation of products and services to ensure profitable continuity of the enterprise. In essence it is a political job and requires highly individual skill (34).

2.6 Factors Leading to the Success or Failure of Innovation

Many management writers comment that successful commercial innovations are usually those where a specific market need is brought to the attention of a creative individual - who is also an entrepreneur. For example, Craver (35) sees the basic requirements for success as

1. A new technology or concept
2. A transfer agent
3. A real market need

In the same publication, Debreyne (36) reports a study of 24 Belgian firms which had successfully marketed product innovations. He found that all cases of successful innovation exhibited three basic elements

1. At the highest decision levels of the firm, a motivation, coupled with a strong management authority.

2. An anticipated definition of the new product comprising :

(i) A clear view of the decisive advantage the product would have for its users

(ii) The conviction that it was feasible

(iii) The will to discourage a too-easy imitation by competitors - which ensured that advanced technology or at least a genuine know-how applied to the product.

3. A reasonably well organized management system.

It is interesting to see that this European study stresses the need for a product which has real technical advantages and refers to the management input only in terms of being 'reasonably well organized'. This contrasts with a U.K. government study (37) which cited 5 conditions for successful innovation, all relating to organizational aspects.

1. Direct linkage of R & D to the financial and marketing activities of the firm.

2. Framing of planned programmes of innovation in relation to the assessment of opportunities revealed by analysis of markets.

3. Technically effective management, which is market orientated and dedicated commercially.

4. Achievment of short lead-times from start to marketing of product.

5. Proper scale of production capacity and size of market in relation to the launching costs of the project.

Burns and Stalker showed that successful firms were the ones which maintained a close link between the designer and the end user. In particular, the most prosperous firm in their study had the engineers responsible for development work carrying out market surveys for their own products (38).

A more recent study - Project SAPPHO at the University of Sussex (39) examined 29 pairs of similar projects, each pair containing one successful and one less successful project. Consistent patterns relating to successs and failure were reported :

1. Successful innovators were seen to have a much better understanding of user needs.

2. Successful innovators paid much more attention to marketing.

3. Successful innovators performed the development work more efficiently but not necessarily more quickly.

4. Successful innovators made more effective use of outside technology and outside advice, but performed more of the work in-house.

5. The responsible individuals in the successful companies were usually more senior and had greater authority than their counterparts who failed.

Another study, reported by Langrish (40), examined 84 innovations granted Queen's awards for technological innovation in 1966 and 1967. Seven factors important to success* were identified :

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* During an interview with the R & D Director of a company which had applied for, and been granted, a Queen's Award, the results of this study were discussed. The R & D Director pointed out to the writer that the application for an Award required contd./

1. Top person : the presence of an outstanding person in a position of authority.

2. Other person : some other type of outstanding individual.

3. Clear identification of a need.

4. The realization of the potential usefulness of a discovery.

5. Good co-operation.

6. Availability of resources.

7. Help from Government sources.

Twiss (41) provides a further list of critical factors important in successful innovations :

1. A market orientation.

2. Relevance to the organization's corporate objectives.

3. An effective project selection and evaluation system.

4. Effective project management and control.

5. A source of creative ideas.

6. An organization receptive to innovation.

7. Commitment by one or a few individuals.

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* /contd.
a lengthy written statement. Naturally, in composing this statement, care was taken to present a history of the product which stressed the skill of the company involved. Also the role of certain individuals might be overstated, or the help received from a Government department over-emphasised. Since the study was based on these written statements, its results may not accurately reflect the real factors involved in the development of successful products.

The difficulty in assessing the importance of all these success factors is indicated by the fact that each writer reports a unique list. Whilst all stress points like the importance of marketing and designing to satisfy a need, other factors, like relevance to corporate objectives or speed of development work, each feature only in a single list.

There are several other studies which help to illustrate this problem. In one carried out by the Centre for Industrial Innovation (42) 53 projects were examined which had been abandoned during development for non-technical reasons. On average two reasons were given for the shelving of each project - 95 reasons in all :

Cause	No. of Cases
Environmental factors :	
Unattractively small market	19
Uncertainty with monopsonistic buyers	12
Unattractive level of competition	11
Uncertainty of suppliers	6
Obsolescence	3
	51
Organizational factors :	
Lacking of marketing capacity or expertise	14
Lacking of production capacity or expertise	13
Faulty communications with associated firm	7
R & D cost escalation	6
Shortage of R & D resources	4
	44

These results are complemented by work done by Gerstenfeld (43) who found that 50% of all R & D projects which fail do so not because of technical difficulties but because of non-technical ones. He studied 91 R & D projects and overwhelmingly the major causes of non-technical failures was found to be the 'lack of a continuing collaborative relationship between marketing and R & D'. Another view of new product mortality is given by Ben Daniel (44) based on his experience in the giant General Electric Company in the U.S. Commenting that probably only one in sixty new product ideas screened is a commercial success, he sees the reasons for this as :

1. Internal corporate review procedures are inadequate and do not fully probe the need for the product.

2. Timing for the technology may be wrong.

3. The company has a narrow market orientation and the product falls outside that base.

4. There may be an organization 'stalemate' as to which company division should take the work forward.

5. Lack of incentive to carry on the work.

6. The company, especially if large, may be generating internal barriers against the successful growth of small business opportunities.

7. The product may, in fact, not be a good one.

This last point seems to be frequently overlooked.

There is a presumption by many observers that the question of the quality of the product is never in doubt when considering success or failure. Similarly, the reason for an organization's failure to innovate successfully is rarely put down to a scarcity of good product ideas.

Another of Ben Daniel's comments is also one which is often overlooked : where he speaks of organizational stalemate. The effects of politics in companies should not be underestimated just because they are difficult to study and comment upon. Burns and Stalker (46) noted that none of the firms which they observed 'was without some serious political conflict dividing it'.

2.7 Models of Organization for Innovation

Attention has been drawn already to a basic classification of systems of organization in Section 2.5, where Mechanistic and Organic styles of management were discussed. This present section discusses some models of organization designed to cope with the problem of getting new products from development through production and into the market place.

An early conclusion from a study of the literature is that there is no universally ideal form of organization for innovation. The nature, size and age of the firm, the size and complexity of the product and the activities of competitors are some of the factors which influence the design of system which is chosen. Twiss (47) looks at alternative forms of organization in some detail. A summary of his comments follows :

1. Organization by scientific discipline

This refers particularly to laboratory work where there might be, for example, a physics department, a chemistry department, etc. This works very well if the object is to acquire specialist knowledge, but lack of urgency will probably limit its value in terms of commercial innovation. The most serious drawback is the lack of cross-fertilization between disciplines which is often important in technological innovation.

2. Project management

Recognizing the need for a multi-disciplinary approach, it is common to appoint one man to co-ordinate contributions to the project. Although project managers usually have little direct authority over the staff involved, this form of organization often works well. Project managers need good political and co-ordinating abilities.

3. Organization by product line

Sub-groups set up (possibly in a central development department) to form new products for various divisions of the company.

4. Matrix organization

The object of this system is to separate the managerial and professional responsibilities for the project. An outline of a typical scheme is shown in Fig. 2.5. This system appears to conflict with two traditional management rules :

- No person should report to more than one manager.
- Responsibility and authority must be equated.

Twiss discounts these problems, commenting that complex industrial situations require new approaches. For the company, this organization means that both managerial and professional needs are pursued, but the balance between the two may be delicate. The project manager exercises his judgement over the total project and he must have qualities as an integrator, decision maker,

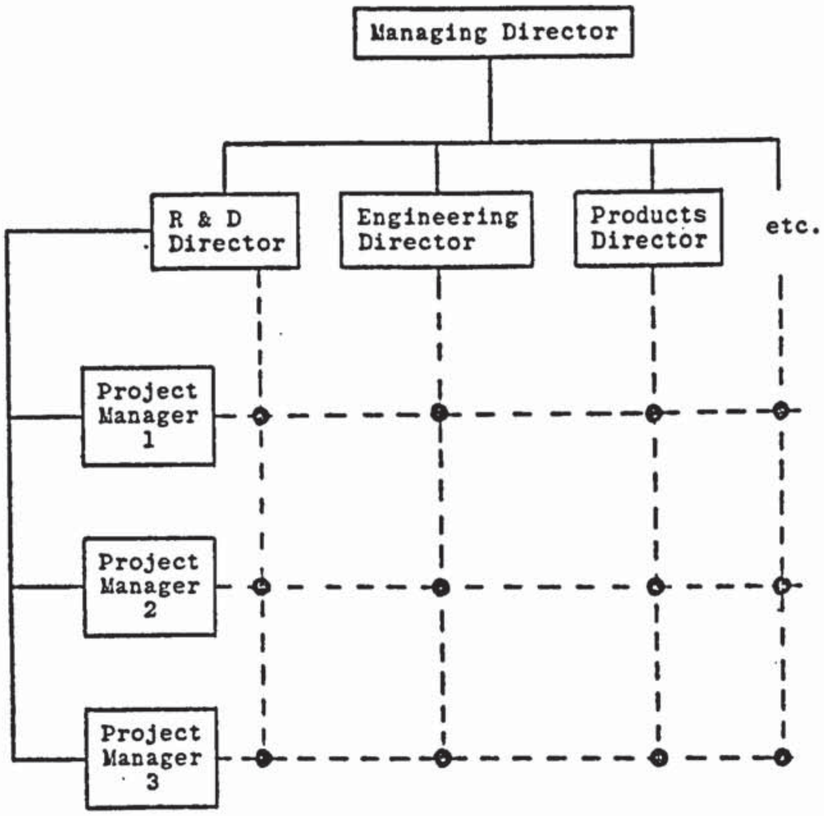

Fig. 2.5 Matrix System of Organization for Product Development

motivator and diplomat. As 'project champion' he identifies very closely with the project and this may make it difficult for him to assess it objectively.

The discipline heads may feel divorced from the 'action' and isolated from the enthusiasms of their staff. It is important that their roles as 'professionals' are reinforced by top management.

The individual worker often enjoys higher status as a member of an inter-disciplinary team than he would if working with a number of fellow specialists.

It is unusual for a Matrix development system to successfully produce useful innovations unless the rest of the company is responsive and receptive to new ideas.

Harrison (48) considers that all companies fall into one of four categories :

1. <u>The power-oriented organization</u>

Strong controls. Creates dis-motivation. Unilateral decisions. Communications soon get blocked when dealing with change.

2. <u>The role-oriented firm</u>

Bureaucratic form. Rules and hierarchy. Suitable for stable environment.

3. <u>The task-oriented firm</u>

Emphasises achievment of goals, without procedural restraint. Flexible, but co-ordination can be a problem.

4. <u>The person-centred orientation</u>

Typical of small firms, particularly of doctors, accountants, etc. Slow to adjust and integrate the efforts of individuals.

Within these categories the 'Task-oriented firm' is the most suitable for dealing with new products, and is likely to provide a fertile setting for a Matrix system (or one of the other innovative systems discussed later in this section). Such systems introduced into firms in the other categories are likely to be unproductive because procedure and bureaucracy will tend to take priority over goal achievment.

Harrison suggests that skilful co-ordination is the key to the effectiveness of an organization and that the form of control adopted is crucial. Matrix systems may not always be satisfactory especially where political or social factors create divisions within the company management structure. Basil and Cook describe an alternative system (Fig. 2.6) which might be used successfully by a change-responsive firm as a method of control.

This modular concept of organization has a number of features. 'Mission-oriented' sub-groups are created to solve specific problems. In theory, either success or failure will then initiate self-destruction - but a problem is that groups may tend to live on to become established and resemble a traditional organization. Similarly, a disadvantage of this modular concept is that mechanistic tendencies can emerge in the project groups. The success of this type of scheme depends on the effectiveness of the 'Mission control centre' which may consist of an individual or of a group. It must channel the expertise and guidance of the functional specialisms into the groups and at the same time, ensure that the results from the groups are adequately evaluated. Perhaps the main advantage over the Matrix system is that the innovation activity may be protected from the pressures of the existing company structure by the mission controller. Thus a modular system might well be successful in any of Harrison's

Fig. 2.6 A Modular Concept of Organization
(From D.C. Basil & C.W. Cook
'The Management of Change'
McGraw-Hill 1974)

categories, although Basil and Cook suggest that only change-responsive firms can be outstanding innovators. Their categorization of features observed in companies of different types (Fig. 2.7) complements Harrison's analysis.

Fig. 2.7 Progressive Stages of Organizational Features
(From D.C. Basil & C.W. Cook)

Mueller (47) also discusses task-oriented structures in some detail. He refers to a modular form as a 'project cluster' where the innovative project is separate from the basic production organization. He comments that the project cluster is now frequently set up outside the parent company. The primary characteristic of this system is that it is designed to encourage creativity. Communications are rapid and organization is committee-form rather than hierarchical. The structure is fluid, job descriptions are flexible and it is usually multidisciplinary. The interface between it and the parent company is critical ; cash and guidance must not restrict freedom. There must be arrangements for the parent to give rapid expenditure approvals and policy decisions - otherwise the sub-group will contain frustrated 'entrepreneurs without authority'. Fig. 2.8 shows Mueller's outline, in five stages, of what he terms the innovative evolution of organization. The move away from a closed system, as shown in Pattern 5, is essential according to Mueller and, in addition, he notes four features which are necessary for success.

1. Leverage at the top - the Chief Executive must deal with uncertainties, not delegate them.

2. 'The need to innovate to grow or to survive' must pervade the organization.

3. Recognition that time needed to effect change will be longer than normally expected.

4. Charismatic leadership with some readily apparent goal.

A further stage from the form of organization described by Mueller in his Pattern 5, is the Venture Concept. This separates further the innovation and existing production functions in the company and also introduces a number of other features. As will be discussed in Chapter 6, the Torque Hose Project was organized for a period on venture lines. In preparation for that discussion, a resumé is now given of some aspects of the literature dealing with the subject.

Aston University

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Fig. 2.8 The Innovative Evolution of Organization
(From R.K. Mueller 'The Innovation Ethic'
AMA 1971)

2.8 The Venture Concept of New Product Development

Many companies now set up innovative projects which are separate structurally and geographically from the main firm. The intention is to allow entrepreneurs the opportunity to experience freedom for their enthusiasm and the potential to grow with a small, new venture.

The concept is based on the theory that big companies stand a better chance of successfully launching new business enterprises if they can create conditions, devoid of bureaucracy, where the motivations of an entrepreneur can be given full scope. In essence, venture systems attempt to simulate the incentives and challenges that small businesses present to those who run them, particularly the prospect of rapid self-advancement. Thus, the most general definition of what is meant by the venture concept of organization is 'the formation of new businesses by tapping existing technical and human resources. It is an innovative form of management that is designed to get away as much as possible from red tape inherent in a large organization' (50).

A venture team is usually set up under the control of a manager whose style is not dictated by the organization of the parent company. Typically the manager and team members are young people who have already demonstrated above-average ability. This is an essential feature of venture groups. Simulation of a small-business environment is reinforced in the U.S. where it is common for all members of the team to invest substantial amounts of their own funds in addition to the company contribution (51). It is likely to be the first opportunity team members have to take such a business risk and their endeavours for success and reward can be expected to be of a high level. On this side of the Atlantic, in keeping with a more conservative business approach, investment by team members is not common. The main incentive is the prospect of early advancement and the opportunity to run a business at an early age. This difference in approach is very important.

Although it is claimed that venture techniques are widely used in many large firms (such as Monsanto, Du Pont and General Electric in the States (52) and British Oxygen (53) and I.C.I. (54) in the U.K.) there is little evidence in the literature of attempts to compare systems and quantify results. Invariably, papers dwell on business successes and make only passing reference to the features of the organization responsible for achieving the success.

However, a useful paper has been published by Hill and Hlavacek (55) which reports on a study of over 100 venture teams in large companies (in the United States). By using questionnaires and personal interviews, a number of unique characteristics were described which distinguish venture teams from traditional forms of industrial organizations. A list of these characteristics helps to define more specifically the nature of venture organizations.

1. Organizationally separate - the most successful new product ventures were geographically as well as organizationally separate - a feature also noted by Burns and Stalker (56).

2. Multi-disciplinary - the interaction of team members with different skills was considered essential for creativity.

3. Diffusion of authority - team members were not confined by job descriptions and were free to develop working relationships. Often team managers were indistinguishable from other members.

4. Environment of entrepreneurship - 'free wheeling' atmosphere together with financial or personal commitment by team members.

5. Top management support - venture team members usually report to managers at the highest level.

6. Market oriented missions - rather than product oriented, but otherwise broad discretion in the method of operation.

7. Flexible life span - lack of strict deadlines.

In his report on a business venture in I.C.I., Vernon (54) covers all these points. In some cases there is qualification or emphasis which one might expect to distinguish a British study from an American one. For example, he tempers the concept of a 'free wheeling' atmosphere with comments about the need for plans to be made carefully and all staff to be 'finance conscious'. If team members have a personal financial commitment, this problem will be self-regulating. But where it is common, as in British companies, for all finance to be channelled from the parent company, it is necessary to have checks and procedures to ensure spending is kept to reasonable limits. Unfortunately, this intrusion of bureaucracy, however slight, can seriously endanger the venture philosophy. Perhaps this is why Vernon stresses the need for the venture manager to create and maintain optimism within the team. He presents a generally hierarchical view of venture organization ; in contrast, Hill and Hlavacek stress the need for the leader to be one amongst equals. In the Dunlop venture experiment, described in Chapter 6, a hierarchical form of organization evolved in the groups. This was probably a perpetuation of existing managerial styles rather than a consciously designed structure.

CHAPTER 3

AN OVERVIEW OF THE PROJECT

3.1 Introduction

This chapter relates the events which took place during the course of the project, in the sequence in which they occurred ; it is the 'story' of the project, In the main, aspects of the work are not discussed at length - this is done in the following three chapters.

Inevitably, a great amount of detail has had to be excluded. Many events and discussions took place which influenced the project, but it would be tedious for the reader if all of these were recorded exhaustively. Instead, the aim has been to provide sufficient information about central and peripheral issues to give a clear idea of the nature of the project and the parameters within which it operated.

3.2 Events Prior to October 1975

In 1972, a Manager at Dunlop's Research Centre at Birmingham was speculating about the properties and behaviour of a hose with an unbalanced cord reinforcement.* It was known in the company that unbalanced hoses would distort when pressurised fluid was used in them. Hoses for all except very light duties, were always made with a balanced construction. Occasionally, usually by mistake, unbalanced hoses had been used with high pressures and the distortion effects observed. However, no measurement of the effects had been carried out in Dunlop as part of any research project.

The Manager felt that if a short length of unbalanced hose was taken and one end was held fixed, then the other would rotate under pressure and perform a useful mechanical function. Thus the concept of the Torque Hose was established and a Research Scientist was assigned to examine the theory of the hose. This he later tested in a number of simple experiments (57).

This work indicated the Torque Hose was worth investigating as a device for use in applications

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* Rubber hoses are commonly reinforced with layers of cords of cotton, nylon, steel etc. When the cords all lie parallel to each other and form a series of spirals in the wall of the hose, at least two layers are normally used so that two opposed spirals are formed. This 'balanced' construction ensures that the hose does not distort when under pressure.

involving fluid pressure where a rotary force was needed. A patent application was made citing the concept and some potential applications (58).

At this stage the Product Development Unit (P.D.U.) at Engineering Group began to be involved in the project. The Director of P.D.U. decided to examine the Torque Hose with a view to using it as a pneumatic device for operating 'bus doors, a current project in the Unit. As no successful design solution had yet been found, the Torque Hose was viewed with enthusiasm.

A meeting was held between Research Centre and P.D.U. representatives on 11th June 1973. It was thought that a hose could be designed to satisfy the specification presented by the potential customer for the 'bus door device - 45 to 55 Nm torque, 90^{o} rotation, 7 bar air pressure, 75mm maximum inflated diameter, 125mm maximum overall length. However, it was felt that the specified life of 10^6 cycles of operation might be a problem and it was decided to commence fatigue testing as soon as hoses could be produced. Research Centre did this whilst P.D.U. was producing a prototype design and model (59).

Two months later Research Centre was able to report that fatigue life of the hose had been increased from an initial few hundred cycles to 50,000 cycles. A number of changes were thought responsible for the improvement, but because of the need to achieve results as quickly as possible, none of the factors had been tested in isolation. Approximately 20 hoses had been tested and it was decided to continue the development by specifying further changes (60). However, it was soon realised that the enormous improvement required to achieve 10^6 cycles was not a reasonable expectation and the project was abandoned.

No further work was undertaken until 1975, when the possibility was explored of using the Torque Hose as an actuator for ball valves. A meeting was held between members of P.D.U. and the Research Centre on 30th January 1975. A new hose specification was discussed and it was agreed that the Research Centre would recommence the manufacture and fatigue testing of hoses. The new specification required 90° rotation, a torque of 27 Nm at a pressure of 5.5 bar and also a 'return' torque (i.e., upon deflation of the hose) of at least 9 Nm. No limit was placed on the length of the hose and a fatigue life of 250,000 cycles was sought. Tests began with hoses 300mm long, 44.5mm internal diameter and 57mm external diameter. By May 1975, after tests had been completed on 12 hoses, it was reported that the specification could be met but further work was needed to assess whether the 250,000 cycles could be attained (61).

Meanwhile, P.D.U. had worked on several designs and was now concentrating effort on the most promising version. With further information on ball valves available, a new specification was produced (62) and

Research Centre was asked to achieve 40 Nm torque at 5.5 bar with 150^{o} of rotation and a life of 100,000 cycles. A prototype was built in P.D.U., but by Autumn 1975, the ball valve idea was shelved. The potential customer who had suggested the application did not maintain interest and P.D.U. found itself heavily committed to other projects. Research Centre decided to continue its hose testing programme and reported completion in June 1976 (63).

During the summer of 1975, the Director of P.D.U., still convinced of the eventual success of the Torque Hose concept, decided to allow the project to be taken over by a Ph.D. student with the Aston University I.H.D. Scheme. On 1st October 1975 the writer joined P.D.U. to begin work on the project.

3.3 Making a Start on the Project

The first meeting of supervisors was arranged for 17th October 1975 giving the writer 2 weeks to become familiar with the project and to outline a plan of work. The immediate task was to make contact with all the members of staff in P.D.U. and the Research Centre who had worked on the project. Through discussions and from reports, it was possible to build up an idea of the progress of the project and to assess the technical data which was available.

Next, thought was given to the planning of the work to be done. A broad outline of requirements was stated in a letter (3) sent from the Director of P.D.U. to the University :

"1) The establishment of rubber compounds, design features such as 'end fittings', for optimum theoretical performance.
2) Practical testing techniques for interpretation of theoretical predictions.
3) The establishment of product concepts cased on the foregoing.
4) A study of market applications and commercial viability of a range of components."

After discussion and consideration, an approach to the project was formulated. Together with a review of the work done already on the project, the intended approach was described in a report (64) prepared for the project supervisors.

The report suggested that the starting point should be a systematic search for potential applications for the Torque Hose followed by assessment of the markets for these applications. It was also suggested that further theoretical work would be valuable so that the properties of a range of hoses could be understood.

Broadly, the supervisors agreed with this approach but doubted whether a search for applications could be successful until better information was available about the basic mechanical characteristics of the hose, i.e., relationships between pressure, torque, cord angle, diameter, etc. Hence, it was decided that the work done already on hose characteristics should be checked and then extended to provide greater information. This work was started by the writer at the Research Centre in November 1975 and continued for several months.

During the test programme, as the properties of the hose became known, some time was also devoted to the search for suitable applications. Study of technical literature and examination of products at exhibitions led to the conclusion that standard pnematic actuators rather than specially designed ones, were normally used in products. Subsequent research into the value of the actuator market showed that, generally, individual applications would not be sufficiently large to justify setting up production of special actuators. This indicated that the previous policy in P.D.U. of designing actuators for specific applications, i.e. 'bus doors and valves, may have been unwise and that the better approach would have been to produce a standard range of general purpose actuators. Consequently, the writer carried out a survey of existing pneumatic actuators to see how a Torque Hose Actuator (T.H.A.) might compete. This is discussed in Chapter 5.

3.4 Design Work

By February 1976 much information about hose characteristics had been recorded. However, the load-bearing limit of the test equipment had been reached and so it was decided to design a new rig. A sketch of the proposed rig was discussed and approved at a supervisors meeting in March 1976. With the assistance of an apprentice draughtsman, detailed drawings were prepared and the rig was built in the P.D.U. workshop. Fig. 3.1 shows a photograph of the completed rig during a test.

Around the same time, it was decided that a portable demonstration rig was necessary for use at presentations. If the project was to be an eventual success, many people - inside and outside the Company - would have to be convinced of the potential of the Torque Hose. Experience had already shown that interest in the device was greatly increased when a working model was available to supplement sketches and verbal descriptions of the concept. So, the writer produced a design for equipment which was mounted in a standard 'executive' briefcase and he then co-ordinated the detailed design and manufacture in P.D.U. The demonstration unit, which is shown in Fig. 3.2, comprises a Torque Hose which gives 90° rotation with 40 Nm torque at 5.5 bar. A lever is incorporated at the rotating end which can be gripped by the observer so that the force generated can

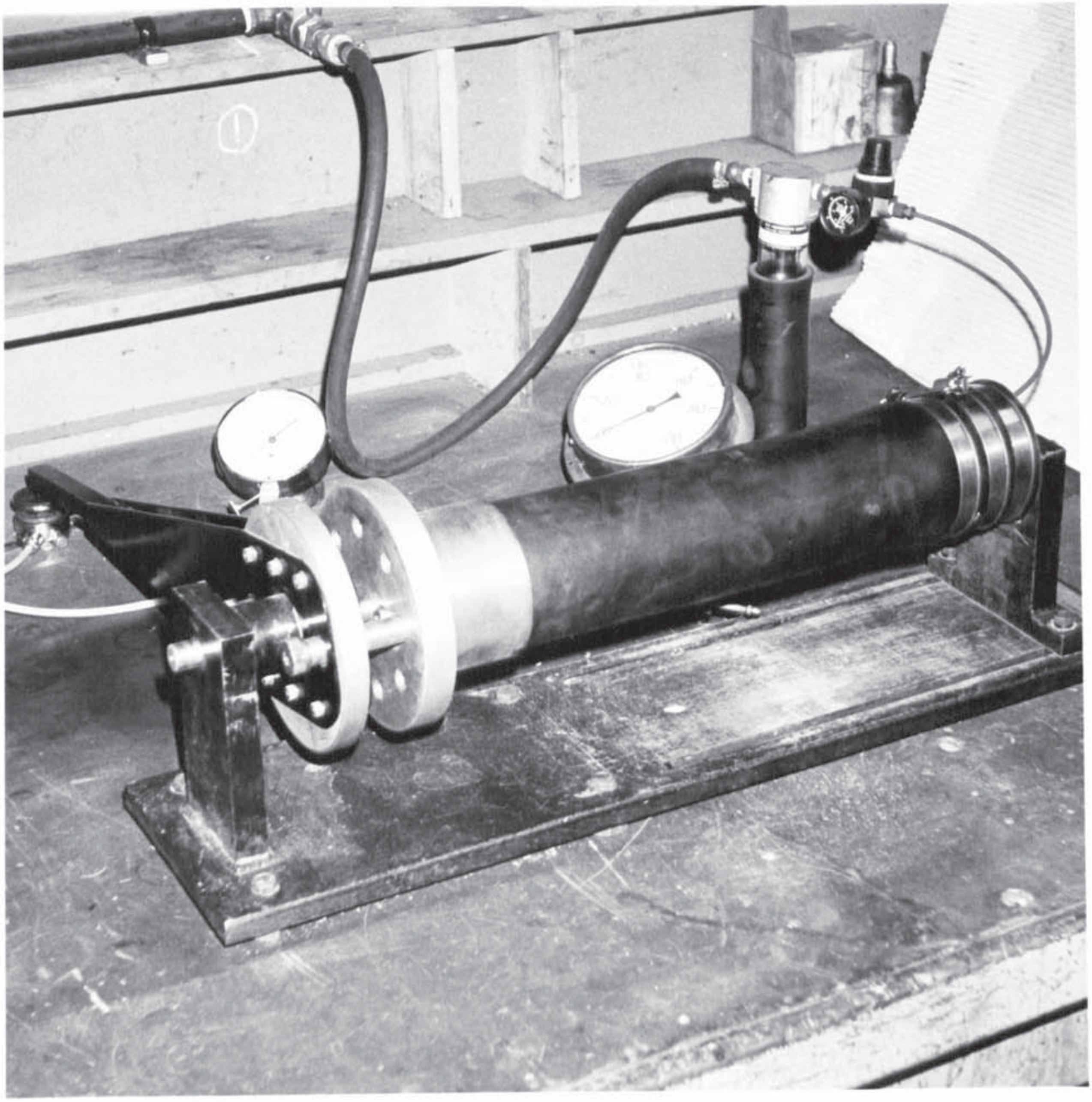

Fig 3.1 Test Rig

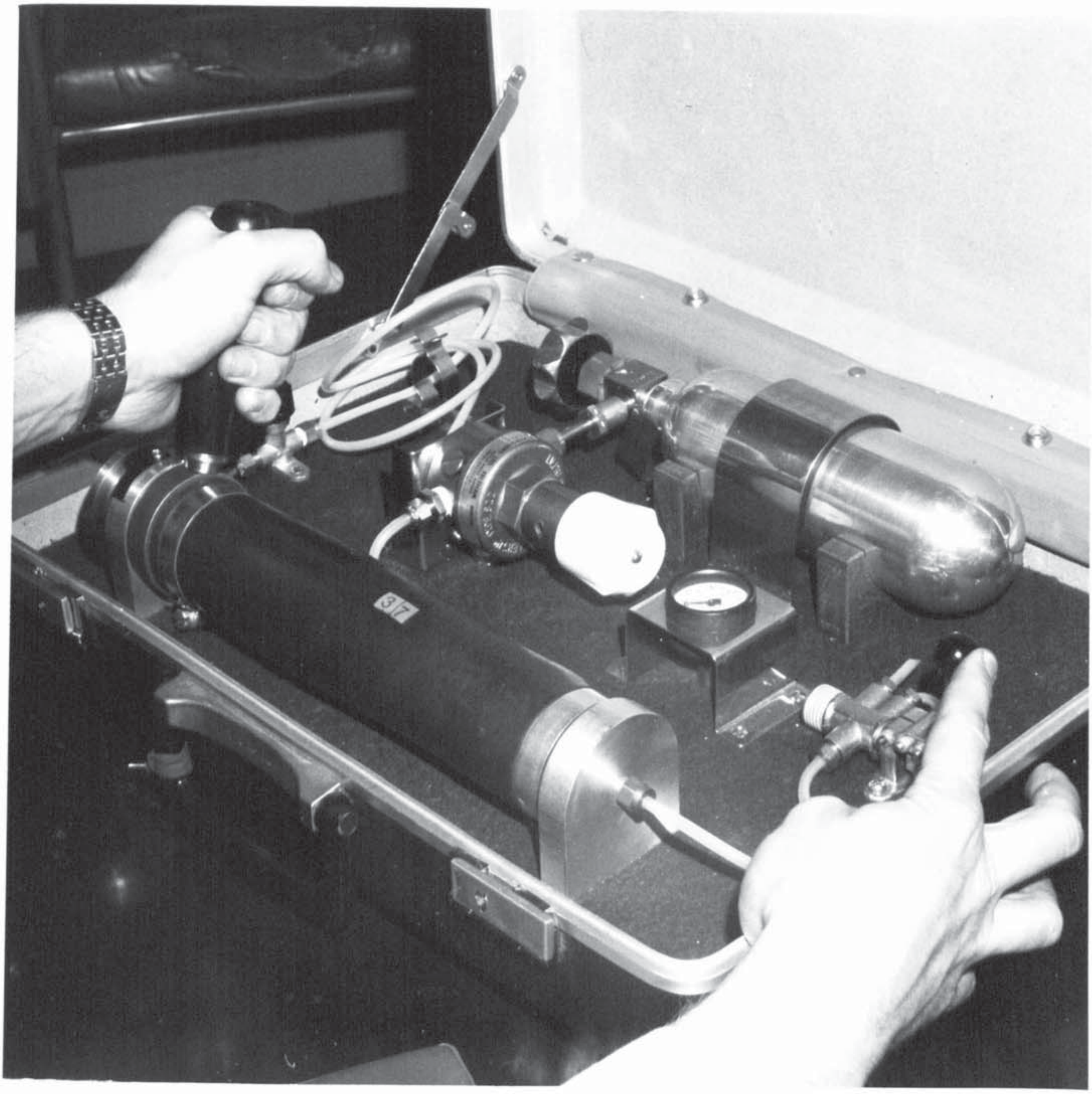

Fig 3.2 Torque Hose Demonstration Unit

be fully appreciated. The compressed air supply is in a small bottle which can be charged to 125 bar. The maximum operating pressure of 5.5 bar is achieved via a reducing valve which incorporates a safety relief device to prevent pressure surges.

After negotiations with Research Centre staff, it had been agreed that hoses of different dimensions (previously one size only had been available) would be built to increase the scope of the test programme. Each size of hose required several items of equipment including mandrels and curing tubes. These were of straightforward design but the process of obtaining suitable material, arranging manufacture, organizing transport and attending to modifications, took a considerable time.

An interesting item of design carried out during the Spring of 1976 was of a prototype T.H.A. From the survey of actuators, it was seen that a T.H.A., using two hoses to achieve forward and reverse powered motion (i.e., double-action) as had been proposed originally by P.D.U. for the ball-valve application, would be uncompetitive in size. The writer felt that the key to reducing the size lay in the elimination of one hose, i.e., obtaining motion in the two opposite directions with a single hose and some kind of linkage. The design sketch shown in Fig. 3.3 achieved this. As the hose rotated through 180°, the drive shaft would turn through 90°. The hose would return to zero on removal

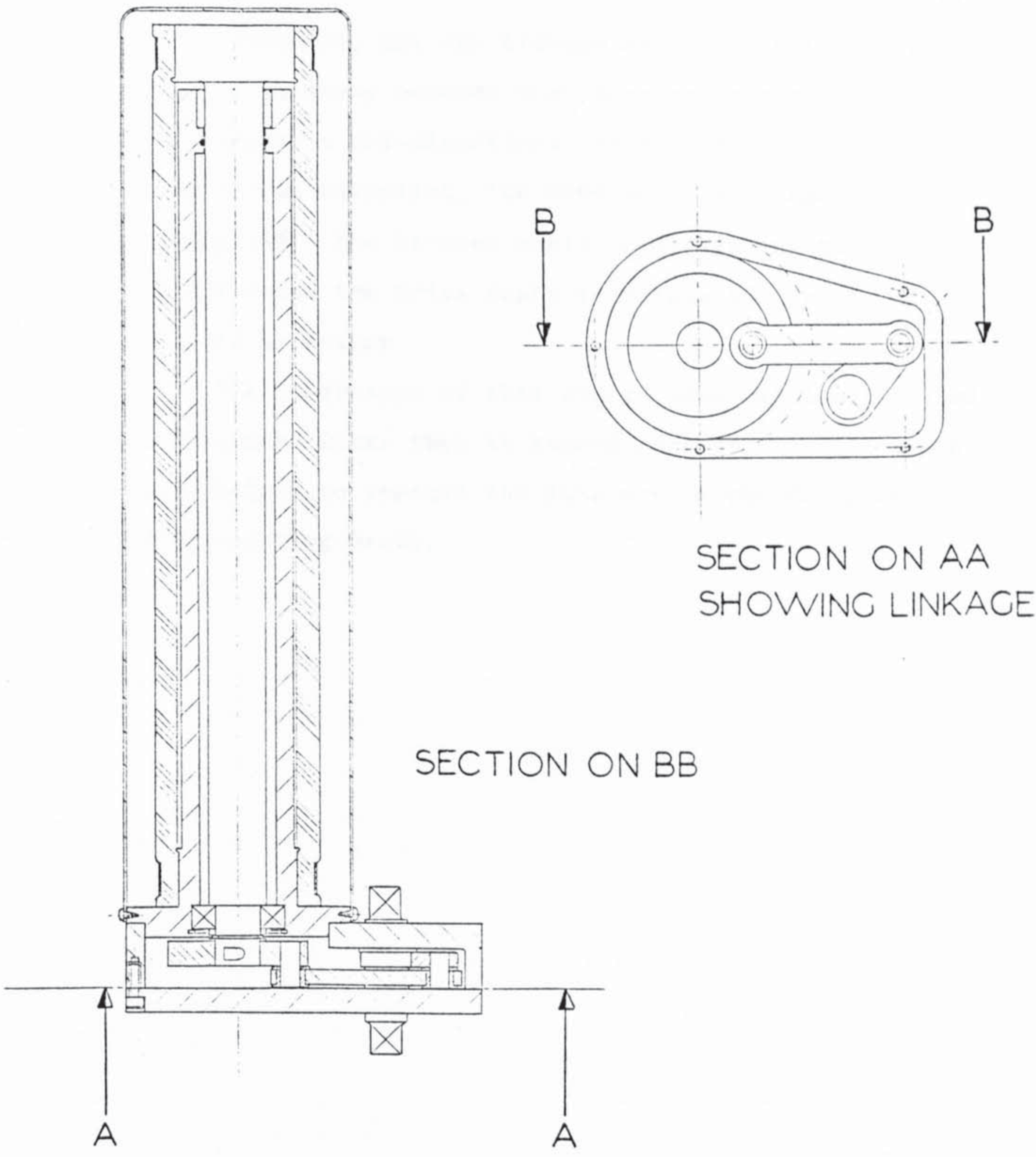

FIG. 3·3: SKETCH OF SINGLE HOSE, DOUBLE ACTING TORQUE HOSE ACTUATOR.

of the pressure, but the linkage and drive shaft would remain stationary because they were connected to the hose through a uni-directional ratchet device. When pressure was reapplied, the hose would move again through 180^{o}, the ratchet would re-engage and the linkage cause the drive shaft to rotate 90^{o} in the opposite direction.

The importance of this design idea was demonstrated a few months later when it formed part of a presentation which helped to capture the interest of the Management of Engineering Group.

3.5 Theoretical Investigation and Further Practical Work

During the ealier work by the Research Centre scientist, several basic relationships had been derived, including one to predict torque values for various pressures, diameters, etc. When this was compared with practical results, reasonable agreement was observed in some cases, but in others there was considerable deviation. It was decided that an improved relationship to predict torque output would be sought and compared with experimental results.

Starting from an examination of appropriate technical literature, the writer was able to develop formulæ to describe the behaviour of the Torque Hose, which he then compared with experimental observation.

After the work had been written up, it was discussed with engineers in Dunlop and in the University. The consensus of opinion was that, because of the nature of rubber compounds, theoretical evaluations were not reliable. Unlike other engineering materials, the properties of rubber are shape and time dependent. For example, the compression modulus of natural rubber can vary by a factor of 300 depending on the shape of the sample (65). For this reason, extensive practica- testing forms the foundation of much development work in the Rubber Industry. It was felt that sufficient theoretical work had been undertaken at this point, and with the completion of the new rig, further tests on hoses were prepared.

The new rig was installed in P.D.U. and by the end of May 1976, experimental work was again under way. One of the objectives of this series of tests was to measure the torque of larger hoses and to compare it with theoretical predictions. Previous tests had used hoses of approximately 50 mm diameter and now hoses of 100 mm and 150 mm diameter were being used. It was found that the method of clamping the ends of these hoses to the rig was only satisfactory for low air pressures. The 50 mm hoses had been secured successfully at all pressures up to 7 bar using 'Jubilee' clips to clamp each end to a plug. Now, the much higher torque loadings were causing the larger hoses to twist out of the clamps.

It was thought that similar, but more robust, clips might solve the problem by allowing greater tightening force to be applied. Suitable products were tested but none could cope with the full output of the hoses. It was concluded that the 'plug and clamp' method was not a satisfactory solution to the problem ; even with the 50 mm hoses the method could not cope with over-load conditions.

While test results were recorded within the limit of the existing end-fittings, attention was diverted to a study of better methods of fixing the hoses. In June 1976 this work was just starting when it was announced that P.D.U. was to close at the end of the following month.

3.6 The First Crisis : Closure of P.D.U.

Although the announcement of the closure was a surprise to most people in the Unit, the decision had been carefully considered by Engineering Group Management. Several events had recently occurred, or were seen to be about to occur, which made some changes in P.D.U. inevitable. The retirement of the Director of P.D.U. was imminent and the Unit had been formed originally to capitalise on his outstanding creative abilities. The major development projects were achieving technical success so further projects would have to be started if P.D.U. was to continue. Finally, a new Group Director (Chief Executive of Engineering Group) had been appointed recently and he was keen to introduce his own ideas about methods of new product development. Hence, having considered the alternative course of retaining P.D.U. with its existing structure, appointing a new Director and embarking on new projects, it was decided to close the Unit and produce new products by other means. In due course, the 'other means' emerged in the form of Venture Groups.

The two major development projects in the Unit, which had now reached maturity and were ready for production, were to be taken over by other divisions within Engineering Group. The fate of other projects including the Torque Hose had not been decided.

The uncertainty of the future of the Torque Hose Project lasted for some weeks. The project was not advanced sufficiently that one of the divisions would take it over, but the P.D.U. Director was keen to see it continue because he believed it had potential. Although his enthusiasm was not shared by other senior managers it was agreed eventually that the project could continue, with a small budget, under his control.*

There was some confusion about which premises and facilities would be used for the Torque Hose Project, but it was clear that the existing work area in P.D.U. would not be available. Faced with 4 or 5 weeks of uncertainty until details were settled, the writer wrote up some of the experimental work and sought advice in Dunlop about end-fittings. At the end of July he took 2 weeks of annual leave and on his return found that the reorganizations were under way. After some enquiry, it was discovered that the new location for the project was a block known, after a previous occupant, as "Bousso's Building". Originally it had been a works surgery and had something of the appearance of a public lavatory. Lately it had been a materials store and now contained much rubbish and was very dirty. Most of the Torque Hose equipment including test rig, hoses, benches and tools

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* Until his retirement, working as Product Development Director he was to be responsible for selecting new products and advising the rest of the Board about the technical aspects of new ventures.

plus the writer's desk and papers had been transferred and left in heaps in this building. Some other items were later found in various different locations, having been mis-directed during the reorganizations.

During August 1976, the new accommodation was made suitable for development work to start again. Walls and floors were cleared of dust and grime, compressed air was installed, electric points were installed, the test rig was reassembled and the last of the rubbish was removed.

While the various batches of workmen were coming and going, the writer had to borrow office space so that he could continue to work on the project. Since no practical work was possible, the time had to be used for work which could be carried out at a desk, i.e. marketing work and technical report writing.

3.7 The Second Crisis : Loss of Confidence

By September 1976, the new work area was finally available for test work to be re-started. Unfortunately, it was clear that the project was considered now to have little future within Engineering Group. There were several signs to support this :

1. The project had been rejected by senior managers in all the divisions at the Coventry site a few months earlier during the closure of P.D.U.
2. Requests to 'borrow' workshop facilities from these divisions were now being refused.
3. The budget for work on the project after P.D.U. had closed was designed to allow the student (the writer) to complete enough work for his study. It was limited to 2 further years and the notional sum involved (£7.500 maximum) would provide very little Drawing Office or Workshop expertise after paying for materials, equipment, patents, etc.
4. No demands were being made for results to be obtained from the project. The atmosphere was of casual disinterest.

In short, Engineering Group had lost interest in the potential new product. If a student and the University had not been involved, the project would have been dropped.

In the context of the aims of the I.H.D. Scheme, it seemed that an academic exercise, as the project had now become, was undesirable. More important than this though, the writer was now convinced from his own work that the new product did have good commercial prospects.

The writer decided to assume the role of 'product champion' and attempt to convince the management of Engineering Group of the value of the Torque Hose project. He had heard much about the need in the Company for innovation and new products. This would be a test of the Company's resolve to explore new products and new markets.

3.8 Presentation to Senior Management

A note was sent to the Group Director and some of his colleagues giving information about the latest technical data on the Torque Hose and the results of the marketing work. In response to this, the Group Director interviewed the writer who argued the case for greater resources to be allocated to the project. The Group Director agreed that the evidence indicated good potential for the new product. He asked for a presentation of the information to his senior colleagues, and with them he would decide what should happen to the project.

The presentation was made by the writer on 4th November 1976. Details were given of

1. Estimated value of the actuator market.
2. Nature of competitors' products and their prices.
3. Technical work completed and required to perfect the Torque Hose.
4. Proposed production method and tentative costings.

The portable demonstration unit (Fig.3.2) and a hastily assembled prototype actuator (Fig.3.4) were shown to the participants.

Later in the day it was announced that the proposals had been accepted. A Project Leader had been appointed with whom the writer and other staff

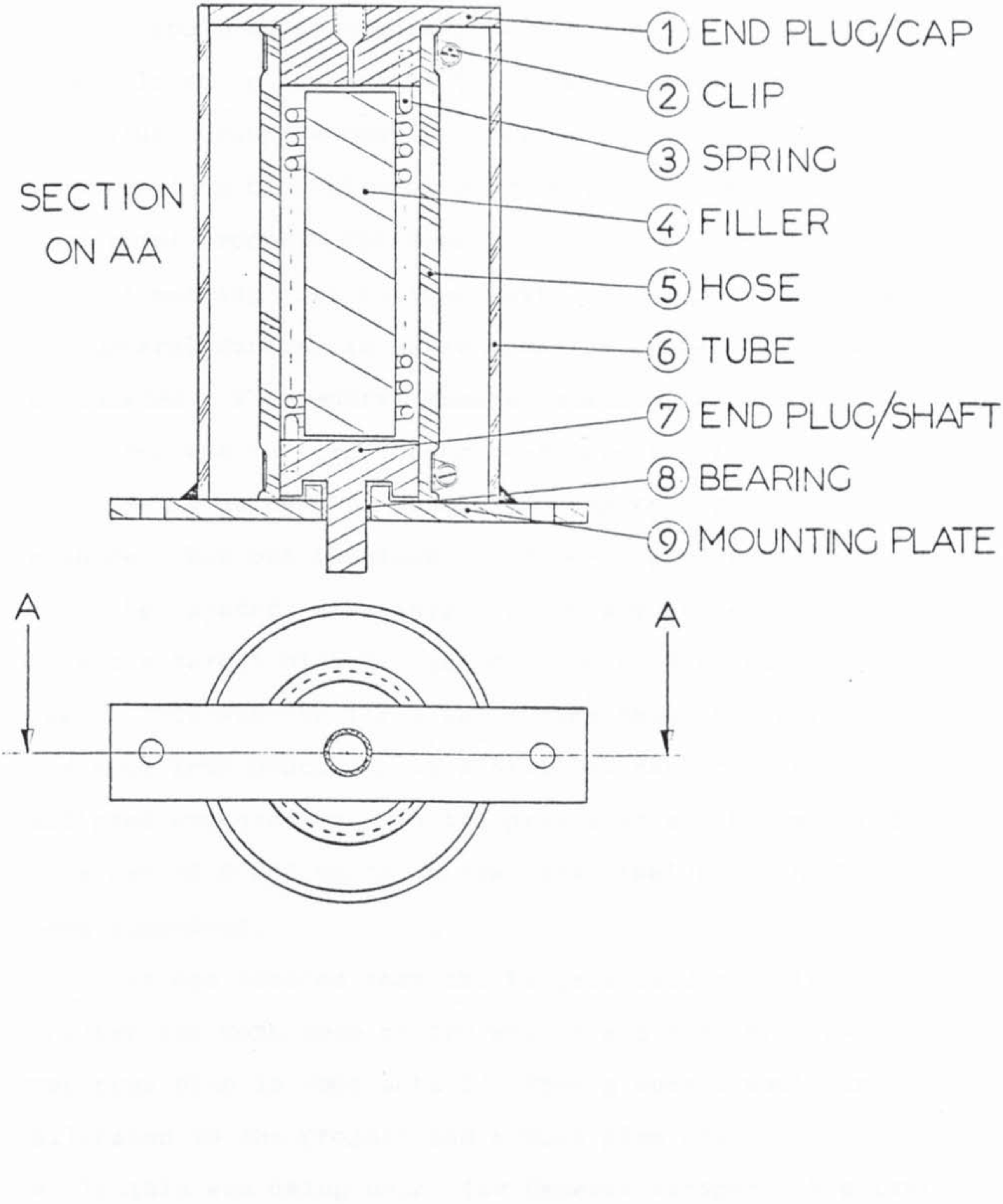

FIG. 3·4: DRAWING OF SIMPLE, SINGLE ACTING, SPRING RETURN TORQUE HOSE ACTUATOR.

(to be appointed as required) would work as a small team. It was planned that the team should operate as a 'Venture Group' alongside similar new product teams in a new section of Engineering Group to be known as the Industrial Products Division (I.P.D.).

A meeting then followed with the Project Leader and the General Manager in whose area the project was now to be located. The General Manager stated that the objective was to turn the project into a trading business as quickly as possible using any suitable methods. His own function would be to give protection from the 'system' i.e. existing company procedures. He set a target of 5,000 units to be sold within one year. This was the first indication that the project had shot from obscurity to a state of dangerously inflated expectation. In the presentation that morning a target of 2,000 units in the first twelve months had been suggested.

It was decided that the Project Leader would analyse the work done by the writer and then draw up a business plan in some detail. Then a budget would be allocated to the project and a work plan drawn up. While this was being done, the General Manager asked that an existing application for an actuator should be located on the Coventry site. This actuator could then be replaced by a specially designed T.H.A. prototype which would give valuable technical information - and also provide a working model to help maintain interest in the project.

3.9 Problems of Bureaucracy

A number of potential applications for the T.H.A. were inspected. One of them was an actuator used to stir paint in the spray shop of the Wheel Division. Work began on the design of the replacement actuator ; this was greatly helped a few days later by the appointment of a third team member, a development engineer. The general design and detailed drawings were all completed within the team and the actuator was built and ready for testing by the middle of December 1976. The exercise had taken 4 or 5 weeks, most of the time being spent in seeking manufacturing facilities and then carrying out the work.

Meanwhile, the Project Leader was working on the Business Plan. This would provide the management with information such as development times and costs, sales potential, capital required and expected return on capital. In producing this, the pressure of the existing company bureaucracy was felt. The Corporate Planning Department intervened with its own lengthy product appraisal form. The Project Leader provided several sets of answers to its questions, but each time the form was re-issued with requests for greater detail. Similarly the Business Plan itself was drafted three or four times before it was accepted. This pressure to produce detailed information meant that so many estimates had to be made about hypothetical aspects, that, in the writer's opinion, the exercise was misleading rather than informative. For example, estimates of detailed manufacturing costs were meaningless until the method of producing the hose had been determined and the best type of end-fitting was known. More disturbing was the tendency for exaggerated expectations to become facts as subsequent editions of the Plan were issued. Hence the fatigue life became 2 million cycles although only 400,000 had then been achieved and the anticipated U.K. market share grew from £½M to £3M. Eventually the Business Plan was accepted, and a budget of £40,000 was agreed for the work in the first twelve months.

Next, the Project Leader's attention was directed to negotiations with two specialist firms, 'Company A' and 'Company B', who had been introduced by the Product Development Director. Engineering Group management had decided that the T.H.A. would be manufactured by Dunlop and distributed through one or both of these companies. Hence, it had been decided to rely on them to provide market data and technical specifications - the consequences of this are discussed in Chapters 5 and 7. The two companies attracted different supporters in Engineering Group and there was some political manœuvering. This meant more visits and meetings and minutes of meetings and reports - all diverting the attention of the team members from the essential development work on the project.

By this time, it was apparent that the Venture concept was already under considerable strain - in a true Venture operation decisions about distribution, for example, would have been made by the team, not by the parent company. Despite this Engineering Group management still insisted that the project enjoyed freedom of action and was being protected from the normal bureaucracy.

At the same time, the 'office relocation syndrome' was suffered again. The writer was still located in "Bousso's Building" where he had a reasonable office and work area. The two other team members were in a different office complex. It was decided that the whole project should move to another area on the Coventry site. The location chosen was a factory building which had been recently vacated. Offices were available but test facilities were not ready for several weeks after the move whilst compressed air and electricity were being installed. So, again, some development time was lost.

Just when the project had settled down, in March 1977, it was decided that some of the offices would be refurbished. The team members moved into spare offices and for five weeks they had to attempt to continue working amidst all the disturbance of rebuilding. Elsewhere in this empty factory, walls were being demolished and pneumatic drills were ripping up concrete floors. The general effect was to make concentration very tiring and difficult.

3.10 A Major Set-Back

Although the paint stirring prototype (Fig. 3.5) had been built several weeks earlier, it was running satisfactorily only from the end of February 1977. There had been initial problems with some of the mechanical components and then testing had had to be stopped for several weeks during the relocations. During March and April the prototype was running and gave satisfactory performance except in the crucial area of fatigue life of the hose. Previous work at Research Centre had suggested that lives in the region of 250,000 cycles could be expected. Instead lives of as little as 50,000 cycles were being obtained. Hoses being tested on other rigs, recently designed and built, were confirming this disappointing performance.

The two potential distributors were consulted and the general conclusion was that a minimum of 250,000 cycles were necessary for commercial success. Engineering Group management were becoming uneasy about the technical progress being made by the three team members. Anticipated production and sales levels had been exaggerated - as already noted, the potential of the project had escalated during the construction of the Business Plan. Consequently, news of this technical problem was not well received and support for the project began to weaken. The team members hoped that the budget would remain intact and that they

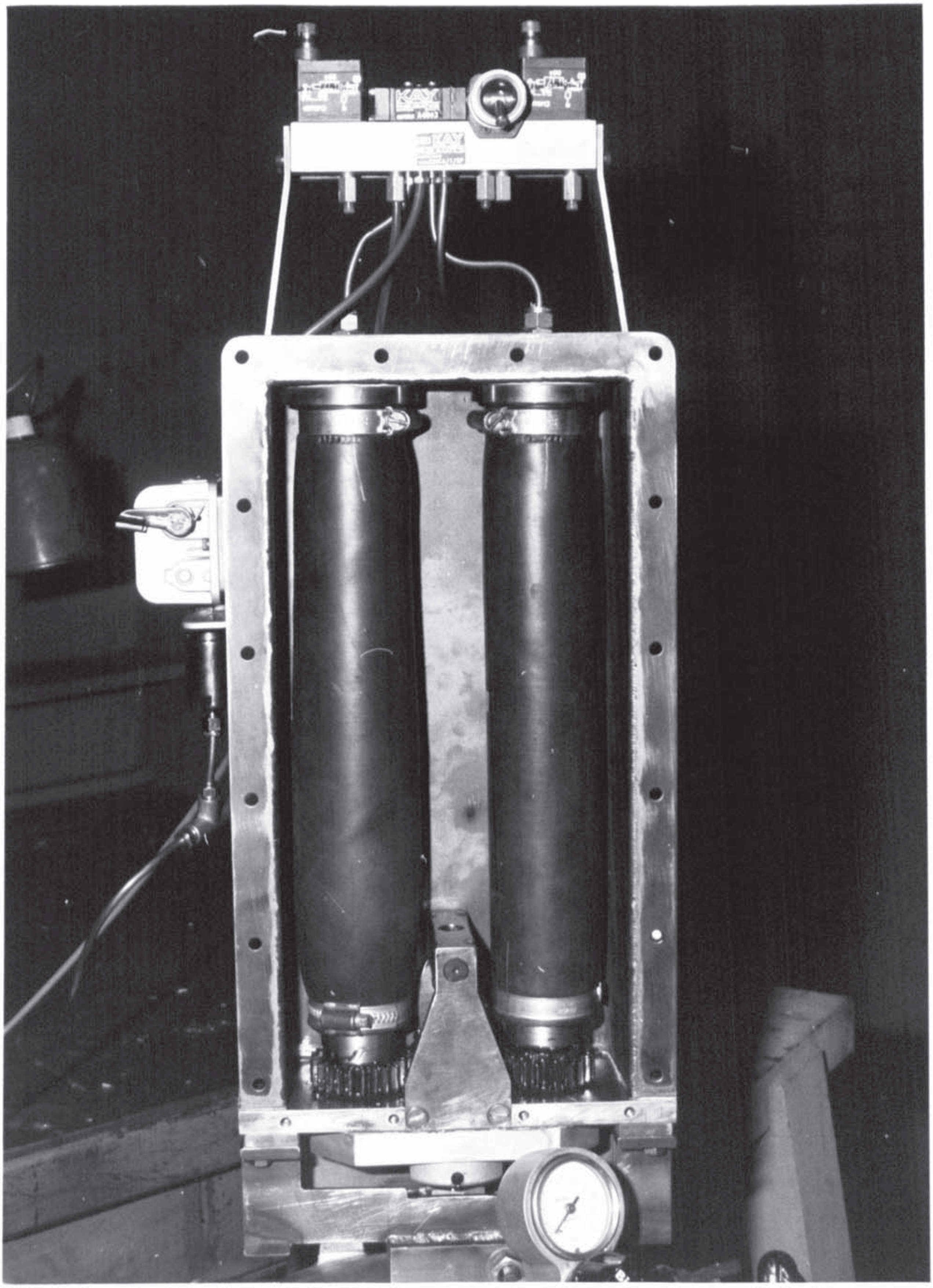

Fig 3.5 Prototype T.H.A. for Paint Stirring Application

would be allowed to tackle the problem. However, faith was badly shaken and for some time it seemed likely that the project was about to be scrapped. Eventually, a compromise was announced. The two members who had most recently joined the project were posted elsewhere. This left the writer once again alone on the project. It was stated that when the fatigue life problem could be solved, the other engineers would rejoin him. The budget was suspended and expenditure was authorised on a day-to-day basis.

3.11 Solution to the Problem Proposed and Tested

It was towards the end of March 1976 when this crisis occurred. A deadline of May 31st was set for a solution to be found to the fatigue life problem. If no solution could be identified, the project would close and the expenditure to date would be written-off.

The first task was to review the action taken at earlier stages in the project when it had been necessary to improve hose life. Several changes had been tried including different rubber compounds and curing conditions. Improvements had been achieved, but because of shortage of time, no changes had been tested in isolation. This meant that beneficial changes could not be identified - except in the case of a rigid sleeve which limited the radial dilation of the hose and reduced the strain in the rubber between the reinforcing cords. The use of this sleeve (or 'restrictor' as it was referred to) had been observed to lead to an increase in life of 100% or more, depending on the diameter selected. Unfortunately, there was a side effect, a severe reduction in the torque output compared with the unrestricted hose. In order to throw more light on this solution and the others previously specified, a meeting with Research Centre specialists was arranged. It had been hoped to hold this meeting quickly but because of the large number involved (11 people), the meeting was not held until 1st May.

In the meantime, the writer had pursued an idea about a novel improvement to the hose construction which might achieve better fatigue life. The basis of the idea was that if the number of steel cords in the hose was reduced, the fatigue life would improve. The reason for this being that with an improvement in the ratio of the volume of rubber to the volume of steel cord, the strain in the rubber would reduce at a given fixed dilation of the hose. (See Section 4.5 for full details).

At the meeting on 1st May, it was agreed that this idea seemed to offer the best chance of obtaining the large fatigue life improvement that was required. Special hoses were designed and manufactured. Testing commenced and by October 1977 it was possible to see some encouraging trends in the results.

In the meantime, some work had been done on the costing of hoses with reduced numbers of cords. It was found that the 'standard' cord configuration resulted in far less expensive hoses than any other configuration. From this cost analysis it was concluded that whatever the improvement obtained, the hoses would be too expensive for use in the proposed actuator. It was decided that the fatigue life would have to be increased by some other means, but that the test programme on the reduced-cord hoses should be completed so that the results would be available for future reference.

Eventually it was seen that the only feasible solution was to revert to the use of a restrictor. An open coiled spring as restrictor, with a specified -

internal diameter, was found to be satisfactory. The spring was necessary, in any case, as part of the actuator to ensure correct reverse operation. In earlier designs it had been placed inside the hose. The major drawback associated with restriction, the reduction of torque output, still remained. This was circumvented by specifying a larger diameter of hose. The size of subsequent actuator designs was therefore greater than had been originally envisaged, but was still considered to be within the limits of acceptability.

This incompatibility between high technical performance and compactness is a good example of the compromises which are encountered during the design process.

3.12 Attempts to Re-Awaken Interest in the Project

By the Autumn of 1977 the writer was optimistic about the technical aspects of the project. For the past few months he had worked steadily to solve the engineering problems. The May 31st deadline had been extended several times until it was eventually removed.

The two other team members were now well established in new projects and there was no possibility of their returning to the Torque Hose project. However, with the technical improvements now obtained, the project was once again promising to result in a saleable product. Much work would be needed to organize for the setting up of production and with the writer's imminent commitment to the writing of his thesis, it was clear that other personnel would have to be appointed to the project. With attitudes apparently firmly set against the project, there was little prospect of this happening, unless a very powerful case could be presented.

It was clear that the strongest case for production would be one which included an indication, preferably a commitment, by Company A of the quantity of actuators which could be sold. (Direct contact with Company B had been lost, although the Product Development Director still maintained an informal link with it). The writer held two meetings with Company A in November 1977. At the first, its Marketing Director acknowledged that, in his opinion, a Torque Hose Actuator with the technical specification now available was a saleable product. Also, that if he was supplied with pre-production prototypes, he would undertake to test-market the product. At the second meeting with the Technical Director of Company A and a Senior Project Engineer, a design which the writer had prepared was discussed and approved. This design was based on the use of several standard components produced and used by Company A in its existing products. Beside the hose itself, the design used only three specially designed components. The building of the first prototype to this design (Fig. 3.6) was carried out during the last few weeks of 1977.

It was hoped that the use of so many 'standard' components would overcome one of the strongest arguments against the product in Engineering Group - that the potential volume of production was too small for economic operation. With only the hose and three fairly simple fittings to manufacture, and the other components available at 'mass production' costs, a good profit margin should have been possible.

However, because of its commitments to other innovative products, Engineering Group was not prepared to set up manufacture of the actuator. A management decision was taken that total licencing rights - manufacturing and distribution - would be offered to Company A.

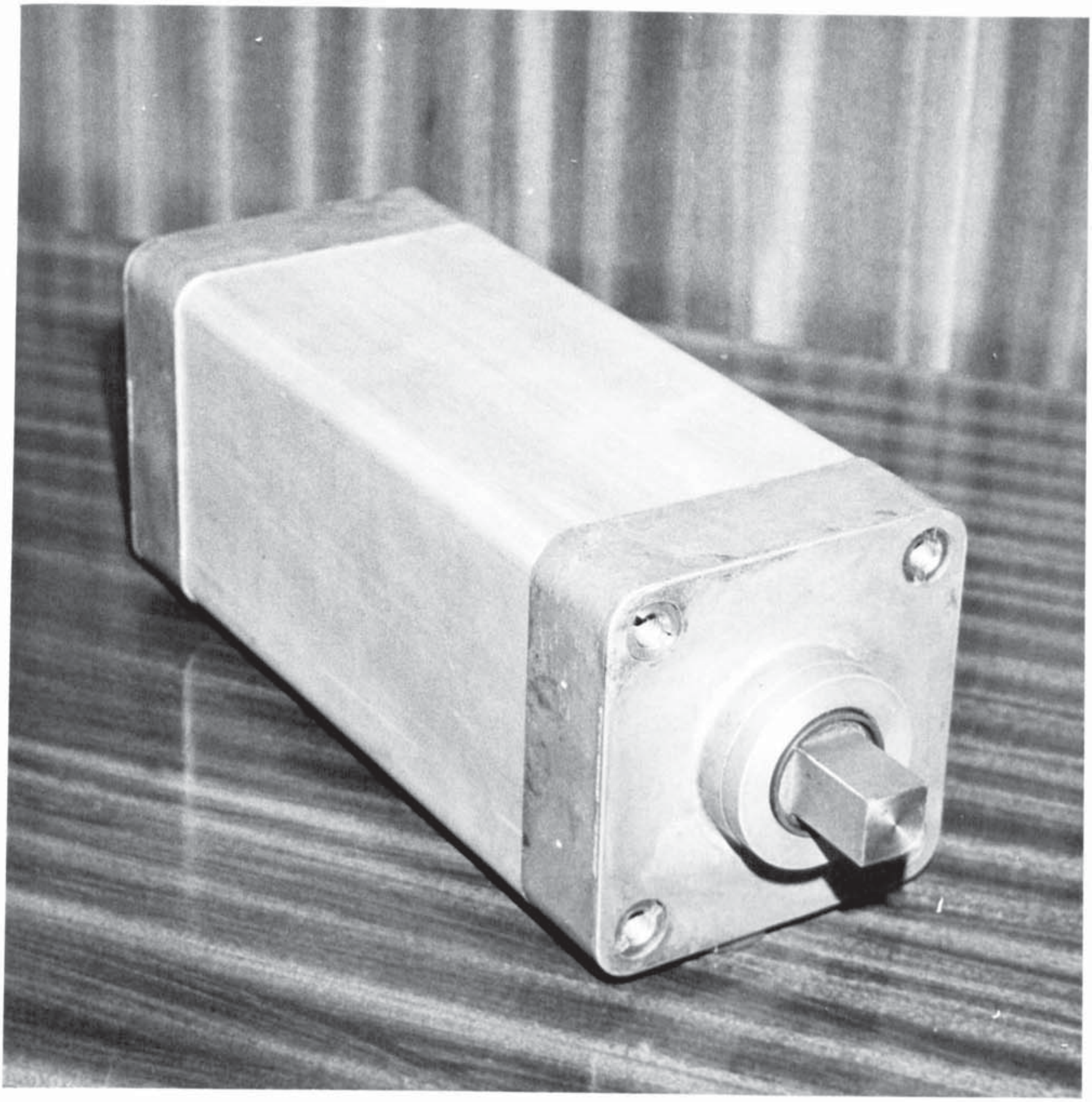

Fig 3.6 Prototype General Purpose T.H.A.

A proposal was prepared and submitted to Company A. Initial reactions were very enthusiastic and expectations were high that a profitable bargain would be achieved. Nevertheless, after considering the proposal, Company A decided not to take up the offer. It was prepared to purchase distribution rights, but it did not have sufficient production capacity to undertake the manufacture of the actuator.

Engineering Group was not prepared to compromise and decided to offer the total licence to other companies. At the time of writing, negotiations are being re-opened with Company B. Pending a satisfactory disposal of the T.H.A., all work on the project has now ceased. The writer's final contribution has been the compilation of a report (66) containing detailed information on all technical and marketing points i.e. as discussed in this thesis. This report will enable the project to be re-started by other workers with a minimum of familiarization.

CHAPTER 4

TECHNICAL ASPECTS OF THE STUDY

4.1 Introduction

This chapter presents the technical work undertaken during the project. It is intended that the chapter should stand complete in itself as a record of a number of items of research, but at the same time, relate to the following two chapters which describe the marketing and organizational aspects of the project.

A brief discussion is included of the technical work which was completed before the writer joined the project in October 1975.

No special section is devoted to the numerous designs and drawings prepared by the writer. These have been discussed briefly in Chapter 3. In fact, design work occupied a considerable proportion of the effort involved in the project, in terms of both researching for data and thinking through designs for best performance. Nevertheless, it is felt that the design work is best presented as subsidiary information in support of the main technical undertakings.

The chapter divides into 4 sections each of which deals with one important topic :

- Characteristics of hoses. This work was conducted by the writer during the early part of the project. The purpose of the work was to provide comprehensive information so that the Torque Hose phenomenon could be properly understood. Also to build up a 'design guide' based on empirical data which could be used when specifying a Torque Hose for use in a specific application.

- <u>Theoretical prediction of hose behaviour and comparison with observation</u>. Following a review of literature, an earlier mathematical treatment of a related phenomenon was extended to describe the Torque Hose. The results obtained were compared with those found experimentally.

- <u>Examination of different end-fittings</u>. A satisfactory method of fixing the hose was required which would both withstand the pressure of the fluid in the hose and also transmit the torque output from the hose. A number of methods were investigated before a solution was found.

- <u>Steps taken to improve fatigue life of the hose</u>. When it was discovered that the durability of the hose was inadequate for commercial success of the product, action was taken to extend the life. After considering the strain levels in the rubber and steel components of the hose wall, a change in the construction of the hose was proposed. In a series of tests an interesting relationship was observed between the spacing of the steel cord reinforcement in the hose wall and the fatigue life.

4.2 Characteristics of Torque Hoses

Information about earlier work on the characteristics of Torque Hoses was available in a Research Centre report (57). The work was in two sections : in the first, observations were reported on the properties of hoses reinforced with nylon cords ; in the second, the properties of hoses reinforced with steel cords were described. The report indicated that the extensibility of the nylon cords allowed the hose to swell greatly under pressure so that early fatigue from rupture of the rubber was experienced. A detailed discussion with the author of the report confirmed that nylon was not a suitable reinforcement. As well as its high extensibility, nylon's ability to bond with rubber was greatly inferior to that of steel. With the large deformations exhibited by the Torque Hose, good bonding was essential - the operation of the hose depended on the configuration of the cords being maintained. Detachment of the cords from the rubber would also cause heat to build up through friction and accelerate deterioration of the elastic properties of the rubber.

The Research Centre report had presented the steel cord results in two graphs. One graph showed a plot of Torque against Pressure (up to 5.5 bar) for the case where there was no rotation of the free end of the hose. The second graph showed a series of curves relating Torque to Degrees of Rotation of the free end for pressures in the range 1.4 - 4 bar. As a start, it was decided to repeat and extend the experiments from which the graphs were derived. In the case of the Torque/Pressure graph Fig. 4.1A results were presented for 90° , 180° , 270° and 360° of rotation as well as 0° . The Torque/Rotation graph Fig. 4.1B was extended to include pressures up to 5.5 bar.

The hose used for the tests had the reinforcing cord layer at a 50 mm diameter and was 300 mm long. The angle of the cord to the axis of the hose was 53° , approximately the angle referred to in conventional hose technology as the 'neutral angle' at which the hose neither lengthens or shortens when under pressure (67). A similar hose had been used in the Research Centre tests. The rubber compound used for the hose was denoted by the number 1621. This compound was chosen by Dunlop scientists because it had properties suitable for the conditions of service that were anticipated for the Torque Hose when commercially designed. In particular, this rubber was highly resistant to deterioration caused by mineral oil, a contaminant frequently present in industrial compressed air supplies. Also it would withstand prolonged exposure to ozone, another serious hazard for rubber materials.

The apparatus used in the tests was built up from items surviving from the previous work. A steel rod approximately 15 mm diameter and 0.5 m long was clamped horizontally. Each end of the hose was fitted with a plug to which it was clamped by a 'Jubilee' clip. One plug had a hole in the centre fitted with an O-ring

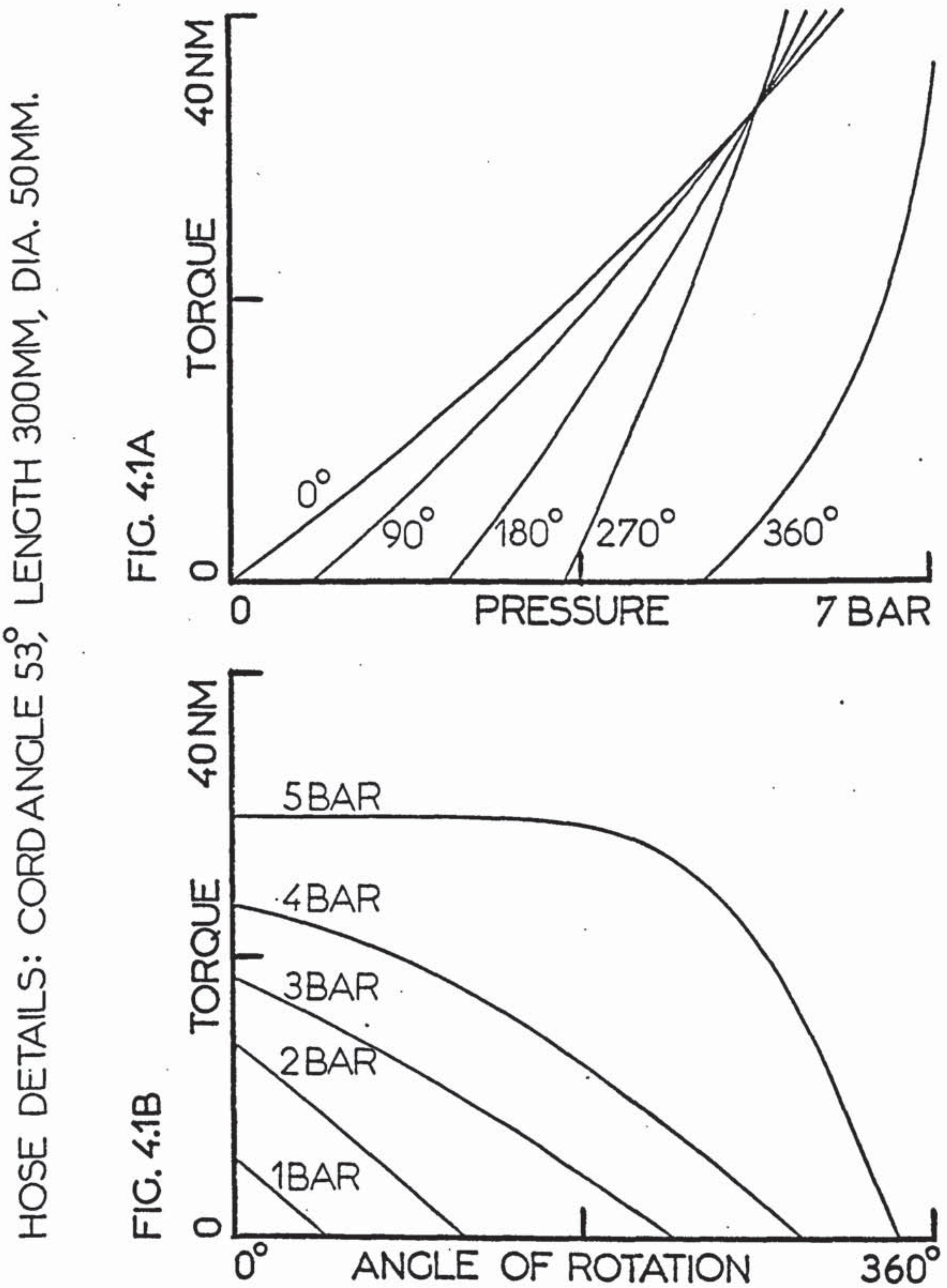

FIG.4.1: GRAPHS OF (A) TORQUE V. PRESSURE AT VARIOUS ANGLES OF ROTATION OF FREE END (B) TORQUE V. ROTATION AT CONST. PRESSURE.

seal. The rod was passed through this hole, until the threaded end of the rod engaged a threaded hole in the other plug. Compressed air was introduced inside the hose through a hole drilled into the rod. As the pressure was increased, the end of the hose fixed to the plug with the O-ring seal was free to rotate around the rod whilst the other end was securely fixed to the rigidly held rod. By bolting an arm of a known length to the rotating end, readings of torque output were made using a spring balance.

The tests were intended to allow accurate measurement of the mechanical properties of the hose and the advice of the Research Centre scientists was sought during the design of the experiments to ensure this. The calibration of equipment was checked (e.g. the spring balance against laboratory weights) and multiple readings of results were taken.

The results of these tests were presented in a report (68) which also gave information of the hose construction and of experimental observations.

At this point, the writer considered the variables which could be usefully explored in a further series of tests :

1. Rubber compound.
2. Wall thickness.
3. Cord angle other than neutral angle.
4. Diameter.
5. Length.

Items 1 and 2 were rejected on practical grounds. The range of possible rubber compounds ran into several hundred and the scope of tests on even a small sample would have been enormous. The advice of experts within the Company was accepted : the compound already selected was well suited to the job. Other compounds might have a different modulus of elasticity or 'hardness', thus giving slightly better torque/pressure ratios, for example, but such technical improvements would be counterbalanced by a reduction in other properties, such as resistance to deterioration caused by oil or ozone. Similarly,the wall thickness (about 7 mm) had been specified by experienced scientists in the light of other work on rubber hoses. In addition, a special set of curing equipment would have been needed to produce hoses with each different wall thickness to be tested.

By contrast, hoses with any cord angle, item 3, could be produced easily. Research Centre's initial work had looked only briefly at the effect of using different angles. The tests had been limited to water pressure at 2 bar and only hoses with nylon cords had been used. No indication was given of the performance of steel reinforced hoses at pressures up to 5.5 bar (the 'standard' industrial operating pressure). This information would be particularly valuable because it would enable a previously derived theoretical expression for the torque to be tested.*

A request was made for a series of hoses with length 300 mm, cord diameter 50 mm and a range of cord angles. These were provided and, using the same equipment as before, the hoses were tested. Readings of torque, pressure, diameter, length and cord angle were noted. The results were notified to the Company in a report (69) and are presented graphically overleaf.

Fig. 4.2 shows the torque output and the changes in length and diameter for pressure up to 6 bar. The trend to higher torques at low cord angles is evident but is more clearly shown in Fig. 4.3 where the theoretical torque is also plotted. It can be seen that the observed torque is a maximum at around 35^{o} , falling to zero at lower angles. This can be explained by the effects caused by the clamping arrangement : a length of the hose at each end was prevented from distorting by the influence of the clamps. They left a short central portion of the hose free to distort. For hoses with very shallow angles (i.e. 15^{o} , 28^{o}) this central portion was too short to contain sufficient reinforcing cord to allow full torque to develop.

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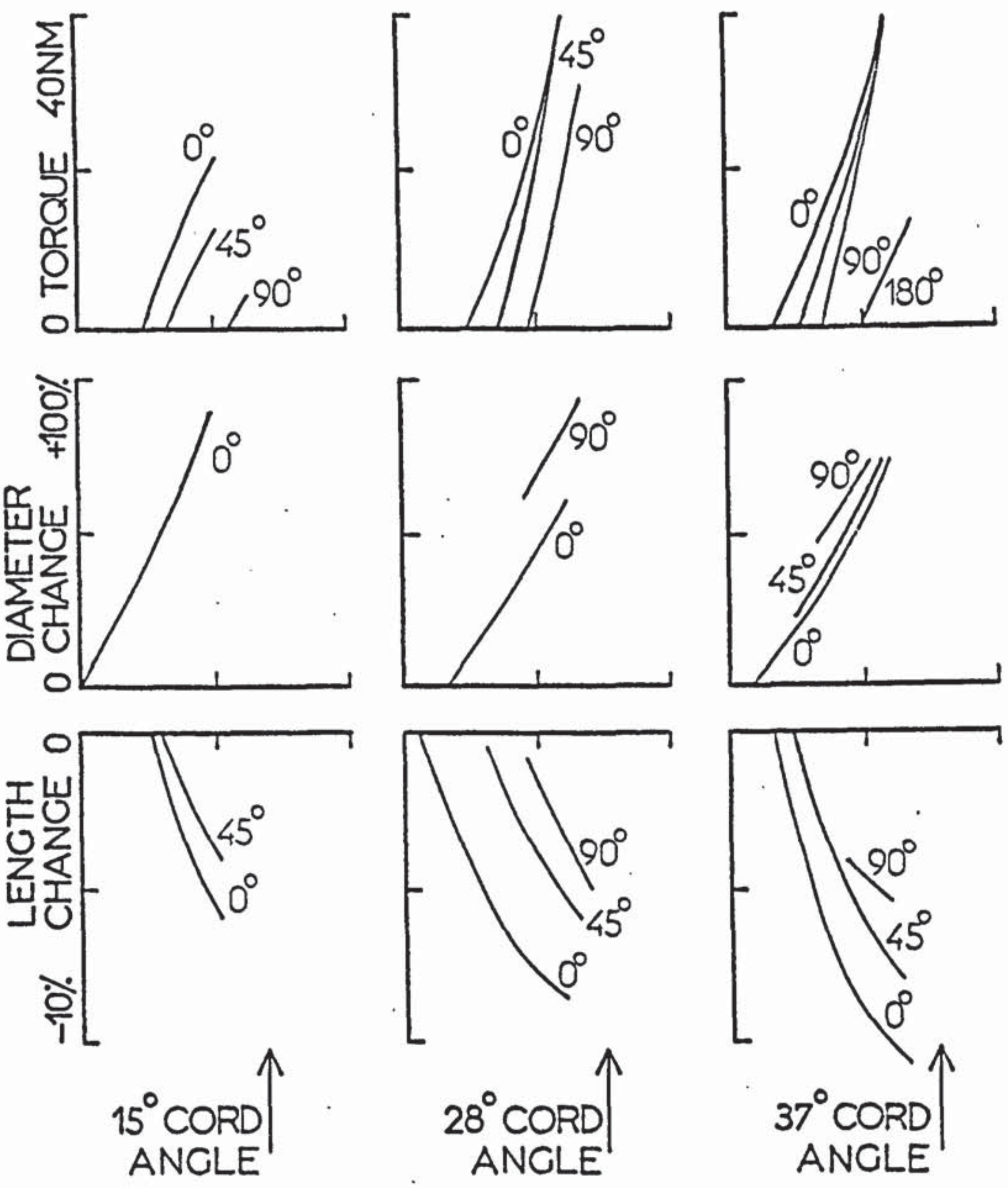
* The expression, derived during the earlier Research Centre work, was :

$$G = 2 R^3 P \cot \alpha$$

where G is the torque, R is the radius of the cord layer, P is the internal pressure and α is the angle to the hose axis of the cords.



NOTES: 1. EACH HORIZONTAL AXIS REPRESENTS PRESSURE RANGE 0 – 6 BAR.
2. ANGLE IDENTIFYING EACH PLOT INDICATES ROTATION OF FREE END OF HOSE.
3. ALL HOSES 50MM CORD DIAMETER, 300MM NOMINAL LENGTH.

FIG. 4·2: GRAPHS OF TORQUE, CHANGE IN DIAMETER AND CHANGE IN LENGTH V. PRESSURE FOR VARIOUS CORD ANGLES.

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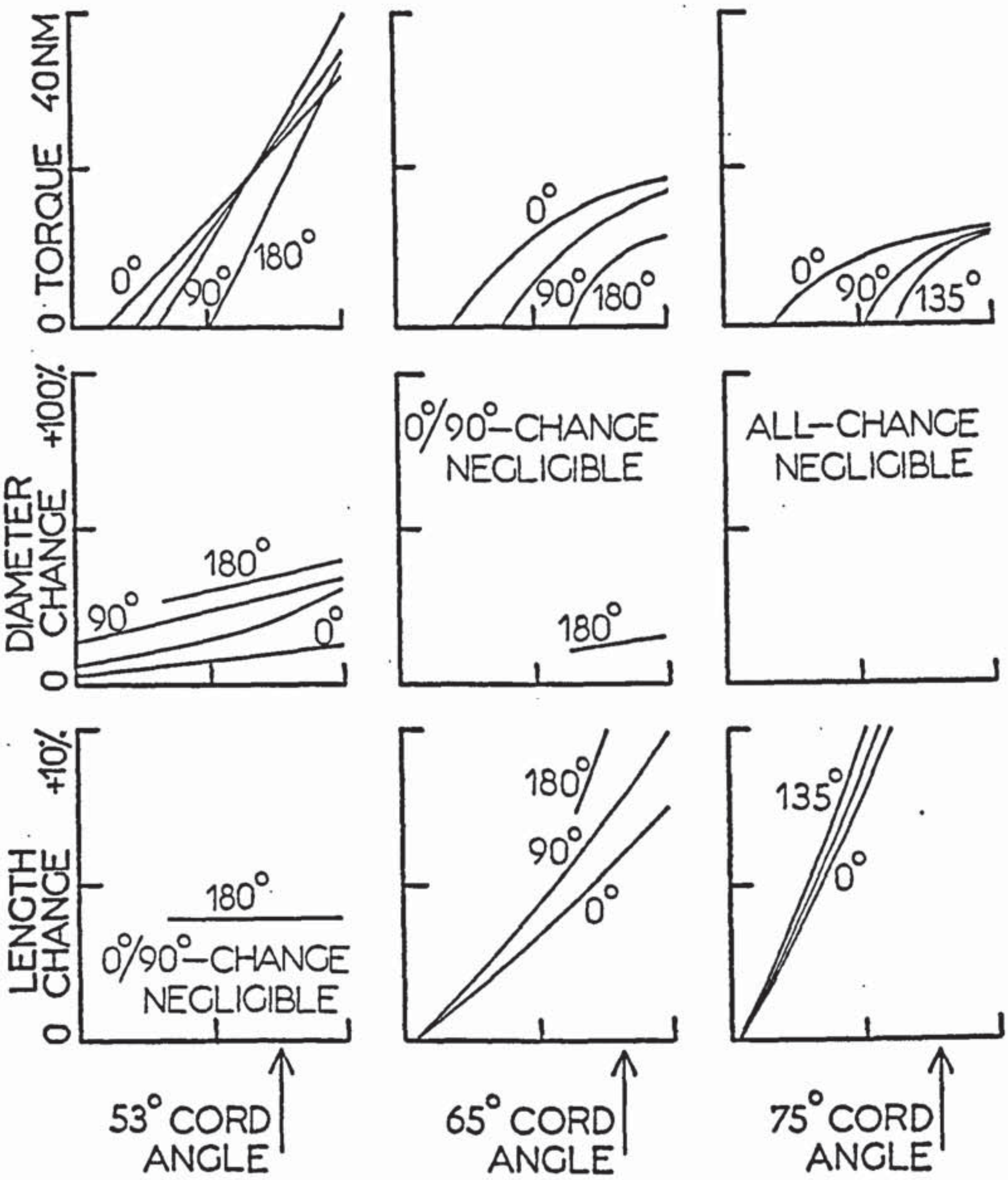
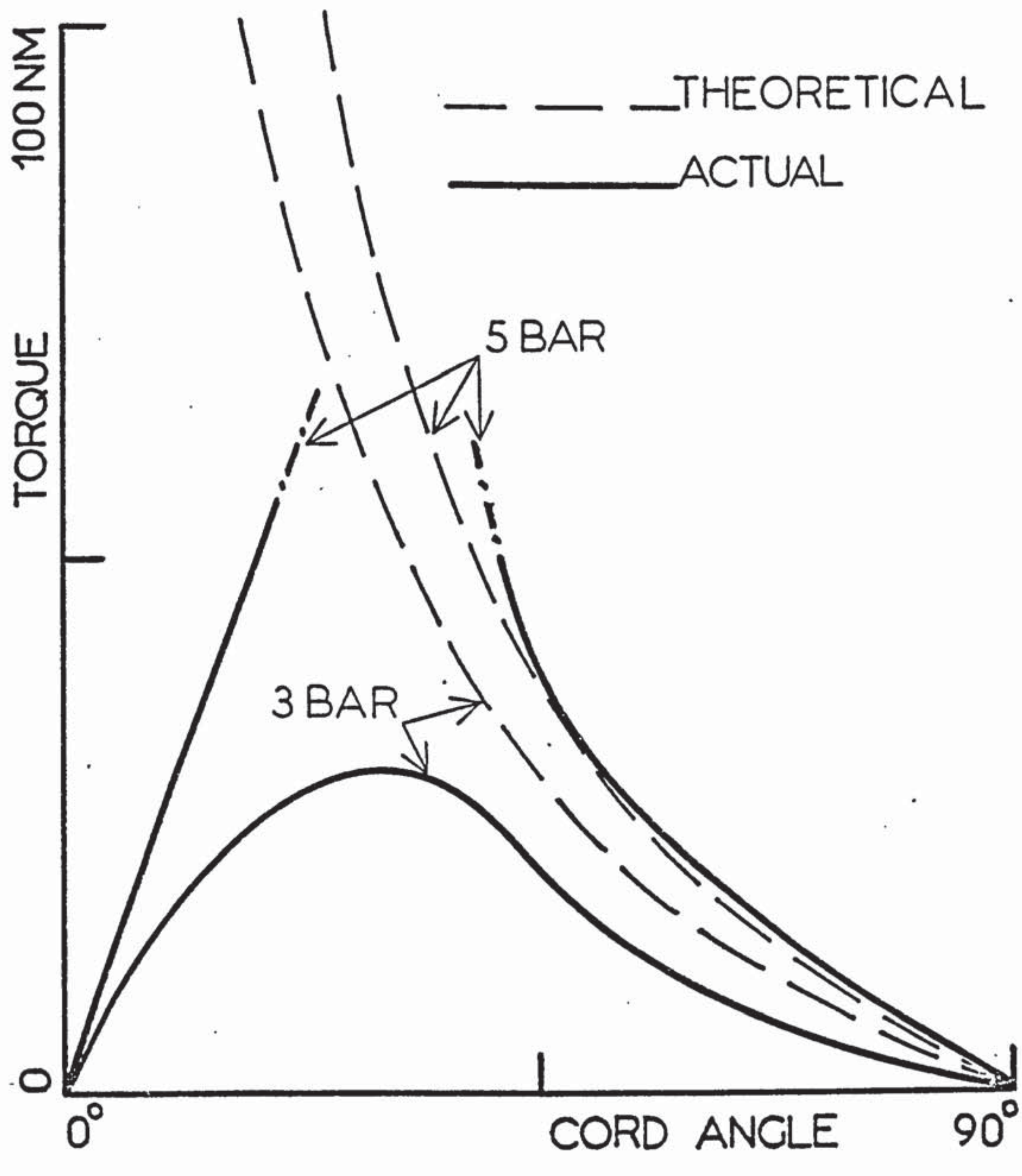


NOTES: SEE PREVIOUS PAGE

FIG. 4·2: GRAPHS OF TORQUE, CHANGE IN DIAMETER AND CHANGE IN LENGTH V. PRESSURE FOR VARIOUS CORD ANGLES. (CONTINUED FROM PREVIOUS PAGE)



NOTES: 1. ALL HOSES 50MM CORD DIAMETER, 300MM NOMINAL LENGTH.
2. THEORETICAL TORQUE CALCULATED FROM FORMULA ON PAGE
3. ZERO ROTATION OF HOSE.

FIG. 4.3: GRAPH OF TORQUE V. CORD ANGLE AT CONSTANT PRESSURE.

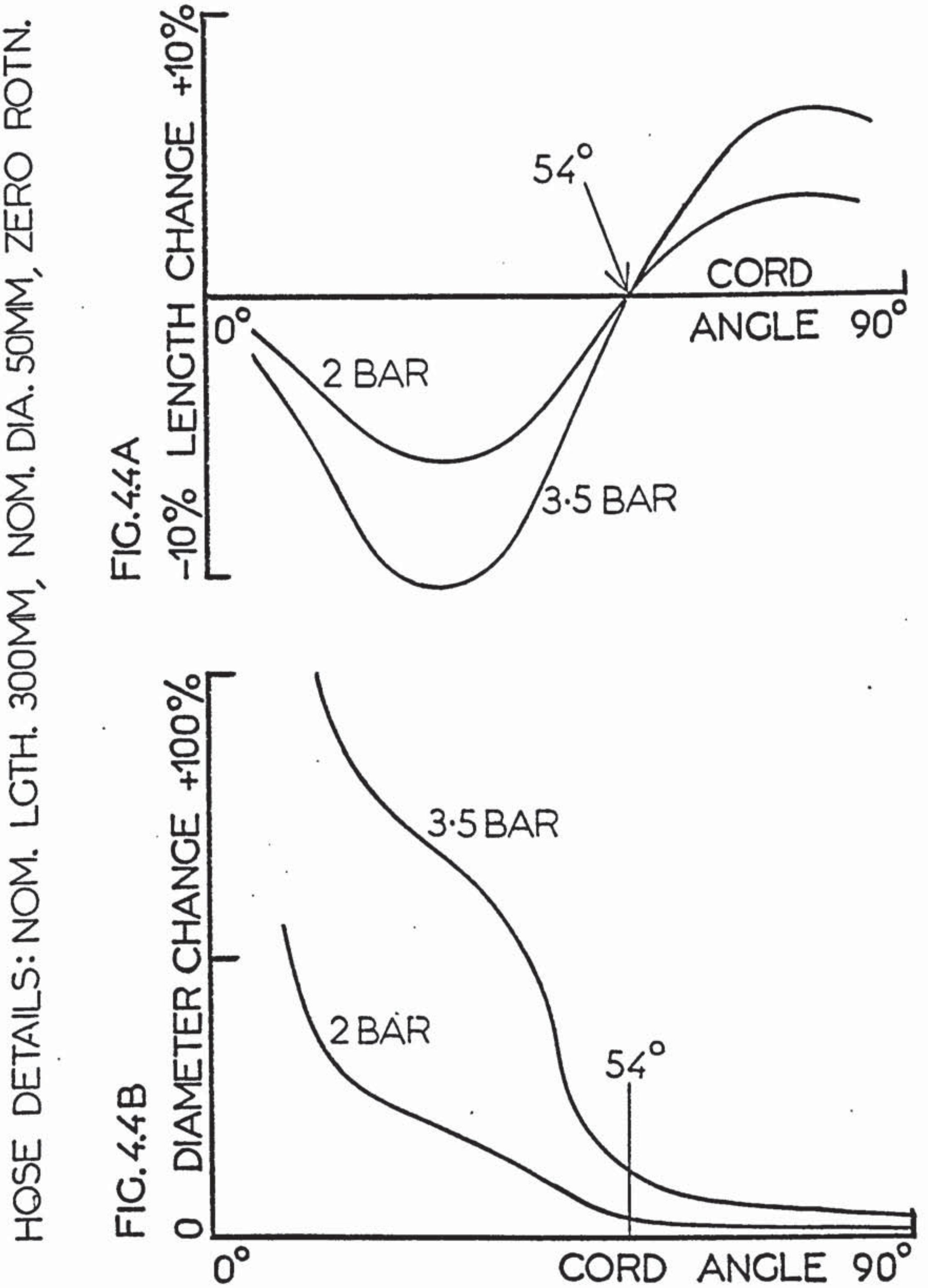


FIG. 4.4: GRAPHS OF (A) CHANGE IN LENGTH V. CORD ANGLE (B) CHANGE IN DIAMETER V. CORD ANGLE AT CONST. PRESSURE.

A longer hose was found to overcome these effects, but already at this stage in the project it was known that a longer hose would lead to an actuator which would be too bulky to compete with existing products.

Fig. 4.4A is a graph relating change in length to cord angle at constant pressure. The neutral angle is evident at about 54^{o} , showing that this phenomenon, associated with conventional hoses, also occurs with Torque Hoses. The last graph in the series, Fig. 4.4B, shows increase in diameter plotted against cord angle. It is clear from this graph that the diameter, and hence the strain in the rubber, increases sharply at cord angles below 50^{o} .

The immediate conclusion from this work was that the 'best' torque from this size of hose was achieved at a cord angle of about 35^{o}. However this also represented the greatest change in length. Below 50^{o} the increase in diameter was so high that unacceptable levels of strain in the rubber would occur. The best compromise seemed to be around the neutral angle where torque was reasonable and the dimensional distortions were minimised.

The final items in the list of variables, concerned the behaviour of hoses with different basic diameters and lengths from those already tested. Up to this point, all hoses had the cords lying at 50 mm diameters ; it was now proposed to test 100 mm and 150 mm diameters. In the same way, a standard length of 300 mm had been used in all tests ; it was decided to examine 50 mm diameter hoses with lengths of 100 mm and 200 mm.

100 mm and 150 mm diameter hoses were made, each with a 53° cord angle. Because of the anticipated magnitude of the torque output, it was clear that the existing apparatus would not be sufficiently strong. A new test rig (Fig. 3.1) was designed and built, and a hydraulic load cell was obtained in place of the spring balance. It was some months before both the hoses and the rig were available. When testing began, the torque output was found to be so great that air pressures had to be restricted to 4 bar for 100 mm and 2 bar for 150 mm diameter. Above these pressures none of the various clips and clamps which were used could cope with the torque. Nevertheless, the results obtained were plotted and extrapolated into the higher pressure region (Fig. 4.5). It was planned to return to these large diameter hoses when a successful end-fitting had been developed, but in due course, marketing information indicated that the preoccupation should be with the smaller hoses.

The final series of tests recorded the performance of 50 mm diameter hoses with 53° cord angles in lengths of 100 mm and 200 mm instead of the 300 mm already used. These results are shown in Fig. 4.6. It can be seen that the 100 mm hose gave little torque beyond 45° of rotation. At this length, the 'end effects' seriously affected the torque performance. It was observed that

NOTE: ALL HOSES, CORD ANGLE 53°

FIG. 4.5

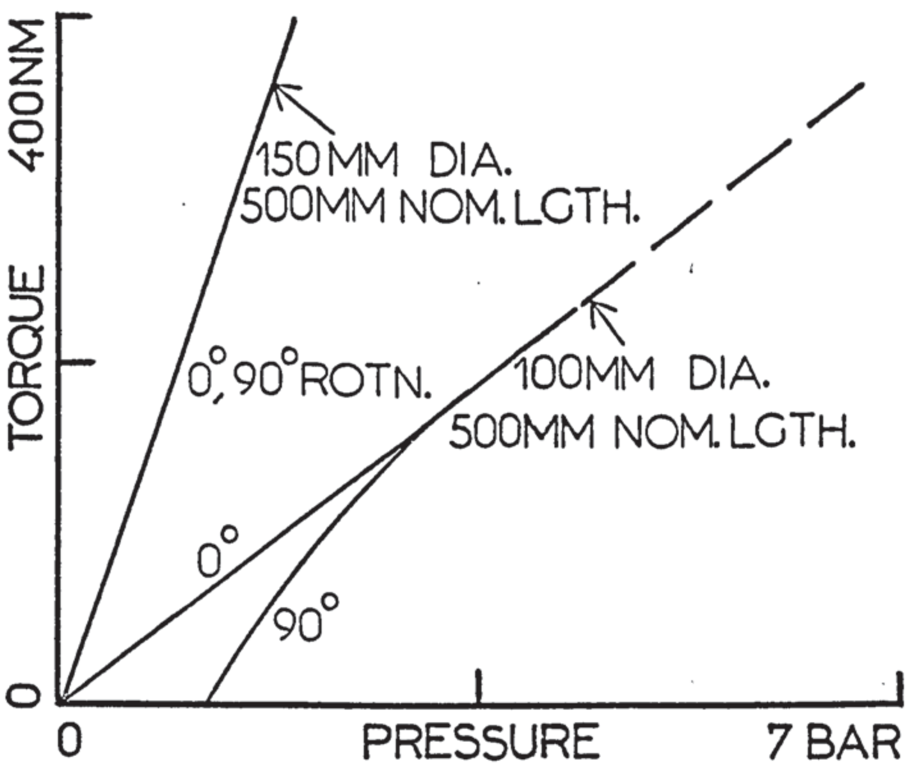


FIG. 4.6

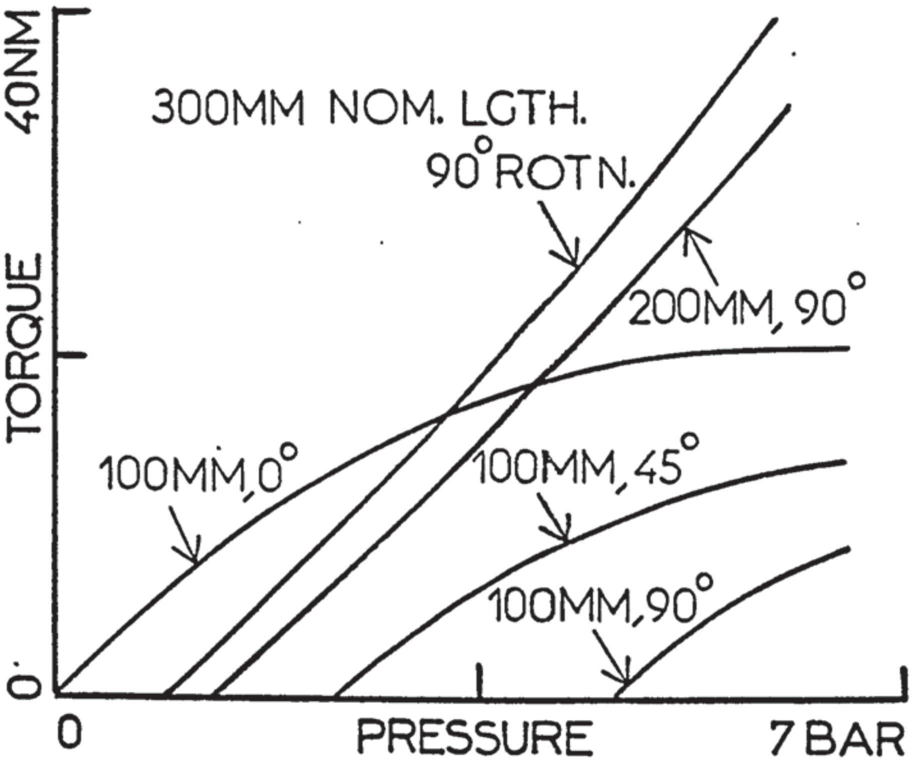


FIG. 4.5: GRAPH OF TORQUE V. PRESSURE FOR LARGE DIAMETER HOSES.

FIG. 4.6: GRAPH OF TORQUE V. PRESSURE FOR VARIOUS LENGTHS OF 50MM DIA. HOSE.

up to 20 mm from the fixing clip at each end, the hose was constrained and could not deform. This meant that the rotation and torque generation were occurring in the central 50 mm or so of hose, thus accounting for the restricted output. The 200 mm length was more satisfactory, showing that at 6 bar a useful torque output could be obtained over 90^{o}, only slightly lower than would have been obtained using a 300 mm hose.

This completed the programme of experimental work designed to investigate the overall mechanical characteristics of the Torque Hose. During the course of the project, the data was frequently used, for example, when specifying hoses for potential applications, when costing exercises were undertaken and when end-fittings were being designed.

4.3 Theoretical Prediction of Hose Behaviour and Comparison with Observation

A formula to predict torque output had been derived as part of the earlier Research Centre work. The results of this theoretical work have been compared with experimental observations in the preceding section of this chapter, where some agreement was found.

In deriving the formula, no account was taken of several effects - the change in cord angle which occurs during pressurisation, the change in length and the rotation of the free end of the hose. The writer extended to the general case the theory already developed for a simplified, particular case. In the course of this work, an inspection of published work was undertaken and a further refinement in the theory was incorporated. The torque available from the hose would be lower than predicted because of the work done in deforming the rubber which encased the cords. Hence, a term was included which took account of this effect.

1. <u>Research Centre Theory</u>

Consider a single layer of thin cords lying at a distance d apart, at a radius b and an angle α to the axis of the hose, as shown in Fig. 4.7

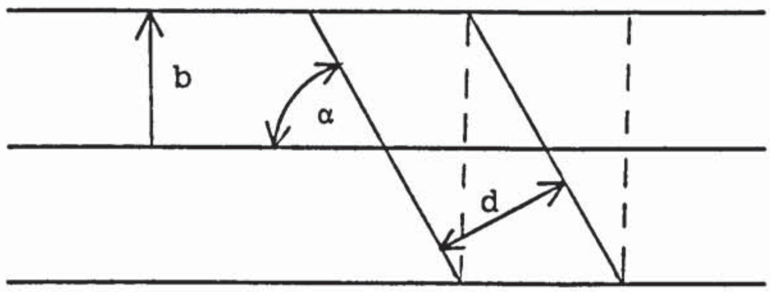


Fig. 4.7

If n_θ and n_z indicate respectively the number of cords per unit length in the circumferential and longitudinal directions, then from inspection of the geometry :

$$n_\theta = \frac{1}{d} \cos \alpha$$

$$n_z = \frac{1}{d} \sin \alpha = n_\theta \tan \alpha \qquad (1)$$

If τ is the tension per cord, then the component of this in the circumferential direction is $\tau \sin \alpha$
The torque per cord about the centre of the hose is

$$\tau \sin \alpha . b$$

and the torque per unit length of circumference is

$$\tau\, b \sin \alpha . \frac{1}{d} \cos \alpha$$

Therefore, the total torque G on the whole circumference is

$$G = 2\pi\, b.\tau b \sin\alpha.\ \frac{l}{d}\cos\alpha$$

$$\text{or}\quad G = \frac{2\pi\, b^{2}\tau}{d}.\sin\alpha\cos\alpha \qquad (2)$$

From the hoop-strength relationship, expressing the cord tension in terms of the internal pressure P

$$\tau\sin\alpha.\ \frac{l}{d}\sin\alpha = P.b$$

Hence

$$\tau = \frac{Pbd}{\sin^{2}\alpha} \qquad (3)$$

Substituting (3) in (2)

$$\underline{G = 2\pi b^{3}P\cot\alpha} \qquad (4)$$

In deriving (4) it was assumed that the cords were inextensible and that there was no change in the dimensions of the hose or rotation of the free end. Also that there were no shear forces in the rubber.

In order to take account of the rotational effects and the dimensional changes which were known to occur, further theoretical work was completed by the writer.

2. A More Comprehensive Theory

The basic undeformed model is as shown in Fig. 4.7 When the hose is pressurised, the resulting deformation can be considered in three parts.

(i) A uniform axial extension of ratio λ

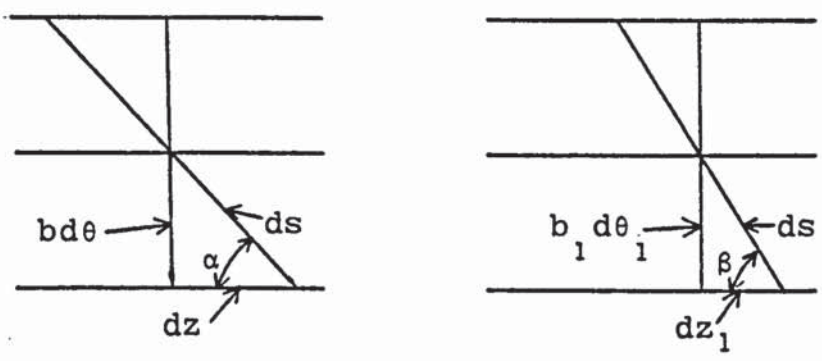
(ii) A uniform increase in diameter of ratio μ. (It is assumed that the wall thickness does not alter and hence that $\mu \neq f\{r\}$).

(iii) A uniform angle of twist ψ per unit length of extended hose.

Thus a point, in polar co-ordinates, initially at $(r\ \theta\ z)$ moves to $(r_1\ \theta_1\ \ z_1)$ where

$$(r_1\ \theta_1\ z_1) = (\mu r,\ \theta+\psi\lambda z,\ \lambda z)$$

After this deformation, the cords make an angle β with the axis of the hose and each carries a tension τ. Since the cords are inextensible, the geometric considerations apply as indicated by Fig. 4.8



$$b_1 d\theta_1 = \mu b.(d\theta + \psi\lambda dz)$$

$$dz_1 = \lambda dz$$

Fig. 4.8

Consider ds an element of length of one of the cords.

Before pressurisation :

$$ds \cos\alpha = dz$$

$$ds \sin\alpha = b d\theta \qquad (5)$$

After pressurisation :

$$ds \cos\beta = dz_1 = \lambda dz$$

$$ds \sin\beta = b_1 d\theta_1 = \mu b\,(d\theta + \psi\lambda dz) \qquad (6)$$

From (5) and (6)

$$\cos\beta = \lambda\cos\alpha \qquad (7)$$

$$\sin\beta = \mu\,(\sin\alpha + \psi\lambda b \cos\alpha) \qquad (8)$$

$$\mu^2 = \frac{1 - \lambda^2 \cos^2\alpha}{(\sin\alpha + \psi\lambda b\cos\alpha)^2} \qquad (9)$$

Let $n\theta_1$ and nz_1 indicate respectively the number of cords per unit length after pressurisation in the circumferential and longitudinal direction. Since the total number of cords does not change :

$$2\pi\mu b . n\theta_1 = 2\pi b . n\theta$$

Hence using (1) (7) and (8)

$$n\theta_1 = \frac{1}{\mu} n\theta = \frac{1}{\mu d} \cos\alpha \qquad (10)$$

$$nz_1 = n\theta_1 \tan\beta = \frac{1}{\lambda d}(\sin\alpha + \psi\lambda b \cos\alpha) \qquad (11)$$

If T_1 and T_2 are respectively the circumferential components of the cord tension per circumferential and longitudinal unit lengths, then by simple resolution and using (8) :

$$T_1 = n\theta_1 . \tau \cos (90 - \beta)$$

$$= \frac{\tau}{d} \cos \alpha \, (\sin \alpha + \psi\lambda b \cos \alpha) \qquad (12)$$

$$T_2 = nz_1 . \tau \cos (90 - \beta)$$

$$= \frac{\tau\mu}{d\lambda} (\sin \alpha + \psi\lambda b \cos \alpha)^2 \qquad (13)$$

From the hoop-strength relationship

$$T_2 = P\mu b$$

Hence

$$\tau = \frac{Pb\lambda d}{(\sin \alpha + \psi\lambda b \cos \alpha)^2} \qquad (14)$$

Substituting (14) into (12)

$$T_1 = \frac{P\lambda b \cos \alpha}{(\sin \alpha + \psi\lambda b \cos \alpha)}$$

Therefore, the total torque along the whole circumference is

$$G_c = 2\pi\mu^2 b.\ T_1.\ \mu b$$

or

$$G_c = \frac{2\pi\mu^2 b^3 P\lambda \cos\alpha}{(\sin\alpha + \psi\lambda b \cos\alpha)} \qquad (15)$$

Substituting for μ^2 from (9)

$$G_c = \frac{2\pi\lambda b^3 P \cos\alpha\ (1 - \lambda^2 \cos^2\alpha)}{(\sin\alpha + \psi\lambda b \cos\alpha)^3} \qquad (16)$$

3. Magnitude of Torque Required to Deform Rubber Material of Hose

Expression (16) represents the torque generated by the cords in the hose when pressurised. Not all of this torque is available for external use ; some of it is used in deforming the rubber material which surrounds the cords in the hose wall. Consequently, a further expression is required to correct for this loss of torque.

In seeking a solution to this problem a search of literature was made. A paper by Chaudhry and Chawla (70) discusses the rotation of a reinforced elastic tube about its longitudinal axis. The treatment of this problem includes a term for the resultant couple associated with the deformation, derived from stress/strain and strain energy relationships. The paper draws heavily on previous work by Rivlin et al. This work was also examined and was found to contain the information required to complete the theoretical analysis of the Torque Hose.

Adkins and Rivlin (71) derive the following relationship for G_R, the couple required to deform the rubber hose :

$$G_R = 4\pi\mu \int_{a_2}^{a_1} \mu r^3 \left(\lambda\mu \frac{\delta W}{\delta I_1} + \frac{1}{\lambda\mu} \frac{\delta W}{\delta I_2}\right) dr \qquad (17)$$

where $W = f(I_1\ I_2)$ = strain energy function

I_1 and I_2 = strain invarients

a_1 and a_2 = radius about hose axis of outer and inner surface respectively of hose wall.

(17) is derived by considering the component of surface tractions in the circumferential direction. This component is obtained when the stress components have been written down. The authors adopt the form of the strain energy function derived for rubber-like materials by Mooney (72).

$$W = C_1\ (I_1 - 3) + C_2\ (I_2 - 3)$$

where C_1 and C_2 are constants

In another paper Rivlin and Saunders (73) show that experimental results confirm the value of $C_2 \approx 0$ and that

$$\frac{\delta W}{\delta I_2} = 0 \quad \text{and} \quad \frac{\delta W}{\delta I_1} = C_1$$

Further discussion of results suggests a value of $C_1 = 1.45\ kg/cm^2$ ($14{,}500\ N/m^2$) for a typical natural rubber compound.

Adopting these results, (17) reduces to :

$$G_R = 4\pi\psi\lambda\, C_1\mu^2 \int_{a_2}^{a_1} r^3\, dr$$

Integrating

$$G_R = \pi\psi\lambda\, C_1\mu^2 (a_1^4 - a_2^4) + \text{constant}$$

As $a_1 \rightarrow a_2$ $G_R \rightarrow 0$ Hence constant = 0

Therefore (17) becomes

$$\underline{\underline{G_R = \pi\psi\lambda\, C_1\mu^2 (a_1^4 - a_2^4)}} \qquad (18)$$

Combining (15) and (18)

$$G = G_C - G_R$$
$$= \pi\lambda\mu^2 \left[\frac{2Pb^3 \cos\alpha}{(\sin\alpha + \psi\lambda b \cos\alpha)} - \psi C_1 (a_1^4 - a_2^4)\right] \qquad (19)$$

Substituting for μ^2 from (9)

$$\boxed{G = \frac{\pi\lambda\,(1 - \lambda^2 \cos^2\alpha)}{(\sin\alpha + \psi\lambda b \cos\alpha)^2} \left[\frac{2Pb^3 \cos\alpha}{(\sin\alpha + \psi\lambda b \cos\alpha)} - \psi C_1 (a_1^4 - a_2^4)\right]}$$

(20)

When $\psi = 0$ and $\lambda = 1$ (20) reduces to

$$G = 2\pi b^3 P \cot\alpha$$

which is the same as (4).

4. Comparison of Theory with Experimental Observation and Discussion of Results

Fig. 4.9 shows graphs of torque against pressure for a 50 mm diameter hose, of length 300 mm and cord angle 53° with rotation of the free end of 0°, 90° and 180°. Each graph shows the experimental readings together with a theoretical plot derived from equation 20. In calculating the torque, a value of $\lambda = 1$ was used. This is the theoretical value for a hose with cords laid at approximately the neutral angle. During the tests only negligible elongation of the hose was noted which also confirms this value of λ . As discussed already values of $C_1 = 14{,}500\ N/m^2$ and $C_2 \simeq 0$ were used. These may be sources of error since they were obtained experimentally using natural rubber test pieces. The rubber used in the Torque Hose was a blend of 50% natural rubber and 50% neoprene (a synthetic rubber) for which no alternative values of C_1 and C_2 were available. Experimental determination of these quantities was outside the scope of the main project and could not be undertaken by Research Centre.

Fig. 4.9A shows quite good agreement between theory and observation. The experimental torque is lower than the predicted torque but, especially at higher pressures, the difference is not great. The other graphs show less satisfactory agreement. In each case, the theoretical and experimental plots can be said to be of a similar

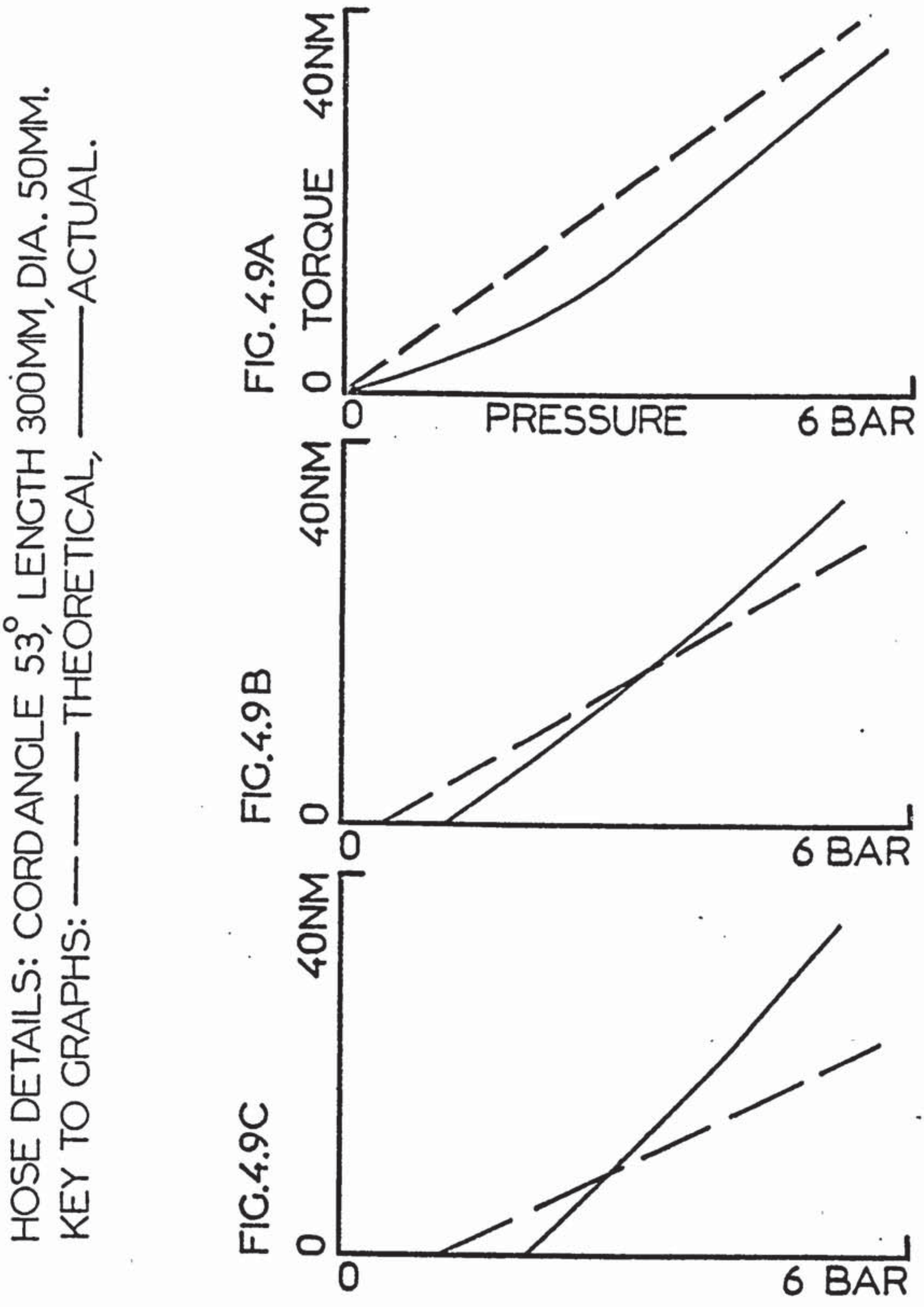


FIG.4.9: GRAPHS OF TORQUE V. PRESSURE FOR (A) 0°, (B) 90°, (C) 180° ROTATION OF HOSE.

order of magnitude but the slopes of the plots diverge considerably, especially in the case of 180° rotation.

At first it was thought that the discrepancy might be caused by an incorrectly specified cord angle. The hoses were built by hand and small deviations from the specified 53° were quite possible. However, when values of α from 45° to 60° were substituted in equation 20 only slightly different theoretical plots were obtained. Other variables were tested but with similar results.

From a review of the experimental procedures, the writer was satisfied that accurate readings had been made. This suggested that the weakness might be in the theory, which was based on the concept of an ideal highly elastic material. In practice, all rubber compounds exhibit effects of hysteresis, internal friction and permanent set, particularly when large deformation occurs. Also, standard reference data for rubber is unreliable. Values of properties may vary considerably between different compounds and, in addition, may be dependent on temperature or the shape of the component being tested. Rivlin and Saunders (73) note that it is difficult to produce a number of moulded rubber samples with identical properties even when the same material and manufacturing procedure are used.

This indicates why research in the Rubber Industry is based on empirical rather than theoretical methods. Experience has shown that the behaviour of rubber is not easy to predict and this is confirmed in the case of the Torque Hose.

4.4 Examination of Hose End-Fitting Problem

During the earliest work on the Torque Hose, it had been found expedient to clamp the hose using simple worm-drive clips, i.e., 'Jubilee' clips. This method had been satisfactory for 50 mm diameter hoses and had the advantage of being inexpensive. However, it was felt that the Jubilee clip was not a proper engineering solution to the problem and when difficulties were experienced with the fixing of larger diameter hoses, it was clear that a superior method was required.

The first work by the writer on the end-fitting problem was an analysis of Jubilee clips to find the maximum safe values of torque and pressure which could be used. This was followed by attempts to seek other types of clips that would withstand greater loads. When this approach did not succeed, a programme of work was begun which tested several different methods of end-fittings. It was during this programme that the writer was joined, from November 1976 to March 1977, by two other members of staff. Hence, this section represents the technical work which was carried out on a team basis.

1. Clip Method

The basis of this method was a Jubilee type clip which was tightened down onto the outside surface of the hose, the inside of the hose being supported by a solid metal plug. In this way a leakproof seal was achieved which enabled 50 mm diameter hoses to function at pressures up to 7 bar.

The writer's first impression was that since this method of fixing worked satisfactorily, there was little point in seeking an alternative. However, tests with larger diameter hoses, which developed larger torques, soon showed the inadequacy of the method. When the results were plotted (Fig. 4.10) it was clear that the use of the method was limited. Even for the 50 mm diameter hoses, the achievment of a safety factor* of 2 x maximum operating pressure was doubtful. A number of clips were tested as an alternative to the standard Jubilee type (more precisely defined as a worm-device clip to B.S. 3628). Some were very expensive costing several pounds each, but none gave performance

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* As a design guide, it had been decided that end-fittings should be capable of satisfactory performance at twice the normal maximum working values of torque and pressure. This overload criterion also applied to other components in T.H.A. designs such as bearings, pneumatic fittings and mounting brackets. This 'safety factor' was adopted after checking the general practice in the pneumatics industry.
In the case of the hose itself, it was considered that the main criterion should be the consistent achievment of at least twice the normal working life.

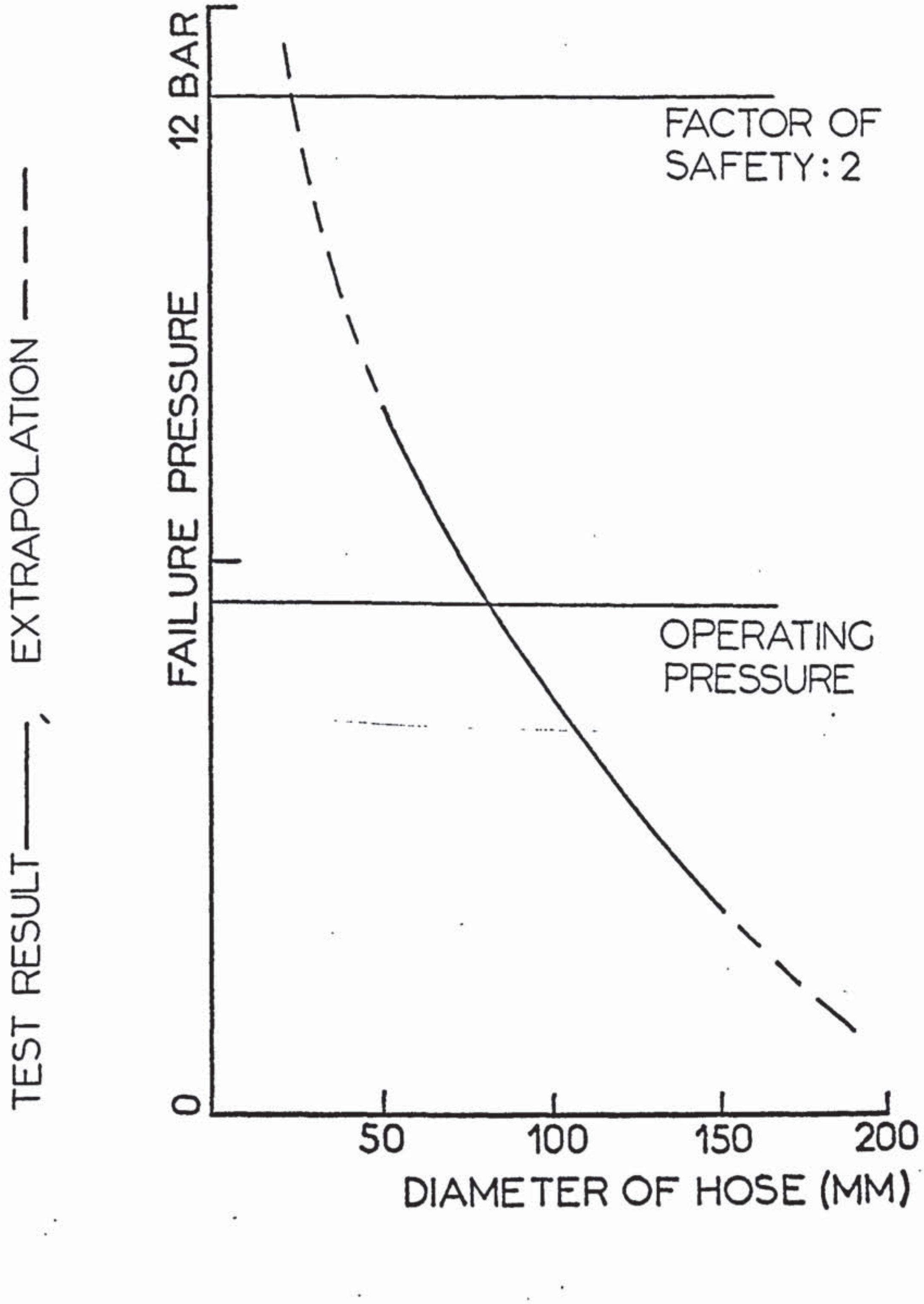

FIG. 4·10: GRAPH OF HOSE DIAMETER V. PRESSURE AT FAILURE USING JUBILEE CLIPS.

substantially better than that recorded in Fig. 4.10. It was concluded that whilst the method was suitable for test work on small hoses, a superior method of fixing the hoses would have to be devised for general use.

2. Adhesive and Bonding Methods

Discussion of the problem with specialists in Dunlop Hose Divisions and the Research Centre produced a number of ideas, one of which was to fix an end-fitting to the hose using adhesive or bonding techniques.

The first step was to approach adhesive manufacturers with details of the problem. It was found that suitable adhesives were of two sorts, 'epoxy' and 'isocyanate' types. Samples of each were obtained. Using a simple fitting with cross section as shown in Fig. 4.11A, 50 mm diameter hoses were tested. In each case, one end was fixed with adhesive, the other with a Jubilee clip.

The epoxy type was 'Chemlok 305'. The manufacturer's instructions were followed, which included a suggested chlorinating treatment of the rubber using a solution made up from hypochlorate and hydrochloric acid. To ensure that any contaminants were removed from the fitting this was cleaned with acetone. When bonded, the assembly was heated to 80^{o}C for 2 hours, to obtain satisfactory curing.

Assembly with the isocyanate type, called 'Avdelbond' was much simpler. This merely required the two components to be clean. The adhesive was applied to one of them and they were brought together for 10 seconds while the bond developed.

In each case, the hose assembly was tested as follows. First, a pressure test in which the pressure was applied in steps up to 11 bar. If the hose and end-fitting survived this test it was then placed in a cycling rig * at 5.5 bar until fatigue occurred. Results are shown in the table in Fig. 4.13. In an attempt to improve upon the poor results obtained, a revised end-fitting as shown in Fig. 4.11B was used to give contact on both the indside and outside surfaces of the hose. The results were still unsuitable, as can be seen in Fig. 4.13. In addition to the very low lives achieved by even the best fittings, was the feature of 'scatter' in the results. Some adhesive fittings failed early in the tests, others lasted longer - but for no identifiable reasons.

Meanwhile, at the Research Centre similar tests had been performed using a Dunlop isocyanate adhesive. These tests were more encouraging. A pressure test was not conducted, but on the cycling rig several hoses reached 300,000 cycles at 90°. This cycling test was not comparable with the one carried out by the team at Coventry because it used a hose which was 50% longer (300 mm instead of 200 mm). The problem of scatter was again encountered, indicating that although satisfactory performance might be obtained in some cases, the method

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* A number of cycling rigs were designed and built for this work. Fig. 4.12 shows a typical example.

Fig. 4.11 Section of (A) Adhesive End Cap
(B) Revised Adhesive End Cap

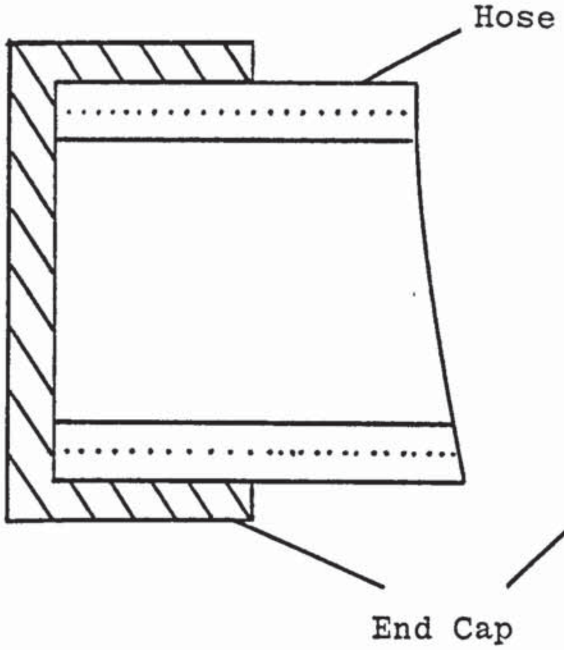

Fig. 4.11A

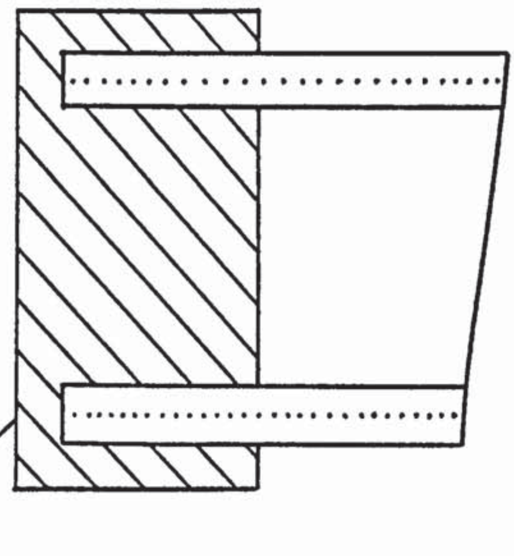

Fig. 4.11B

Fig 4.13 Results of Tests on Adhesive End-Fittings

CHEMLOK 305			AVDELBOND			END FITTING DESIGN
TEST NO.	PRESSURE* TEST	CYCLES TO BOND FAILURE	TEST NO.	PRESSURE* TEST	CYCLES TO BOND FAILURE	
1	11 bar	70,000	1	5 bar(F)	-	ORIGINAL
2	9 bar(F)	-	2	11 bar	12,000	(Fig 4.11A)
3	11 bar	16,000				
4	11 bar	50,000	3	11 bar	6,500	REVISED
5	11 bar(F)	-	4	3 bar(F)	-	(Fig 4.11B)

*(F) indicates pressure test failure.

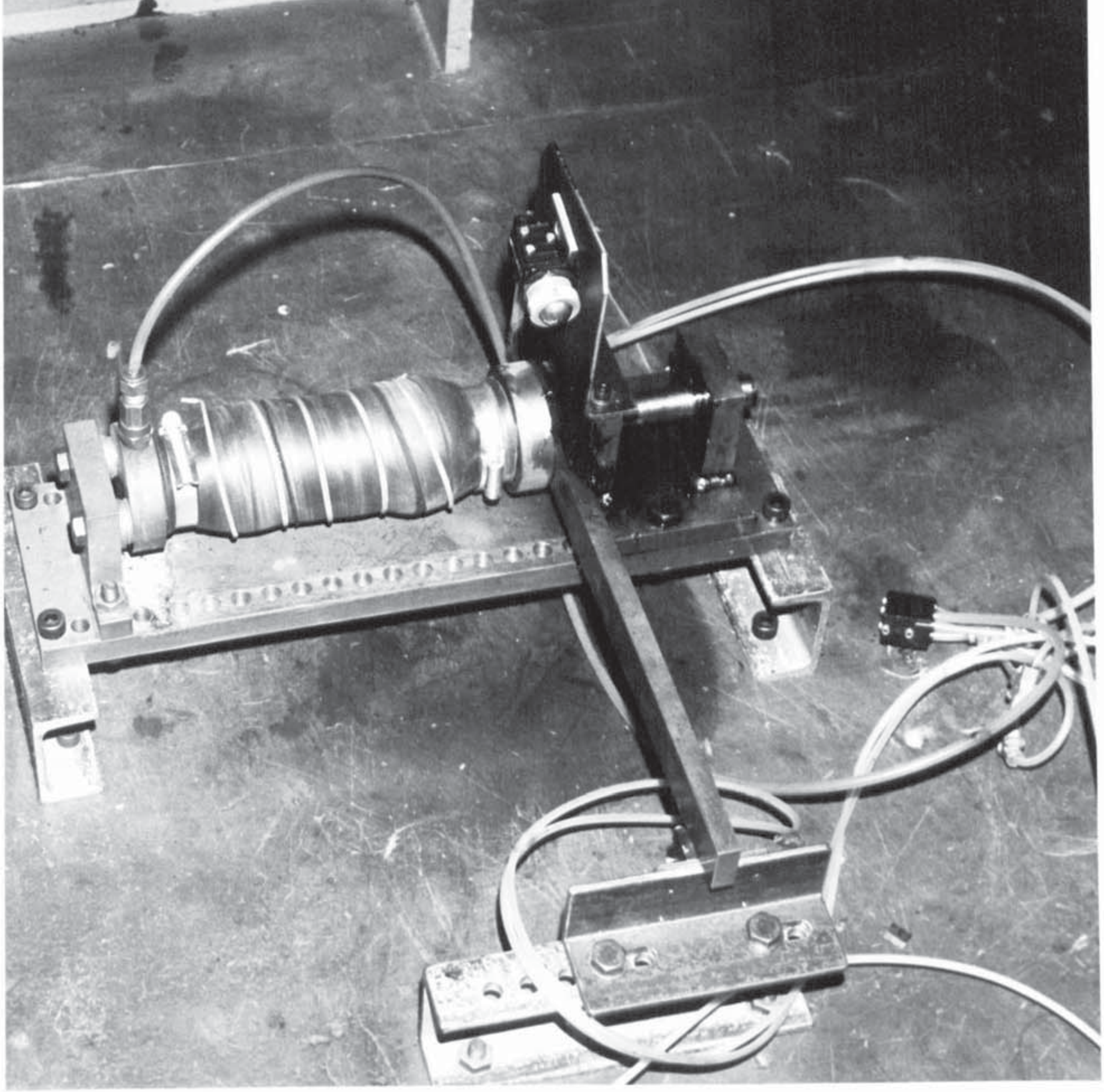

Fig 4.12 'End-Load' Hose Test Rig

was too unreliable for production use.

At this time, several other techniques of bonding the end-fitting to the hose were investigated. One of these was a process recently developed at the Research Centre called 'Friction Bonding'. The method involved rotating a plastic component at high speed and bringing it hard against a rubber one. The heat generated melted part of the plastic fitting and part of the rubber to form a bond. The writer had inspected samples formed by this technique and arranged for tests on the Torque Hose. The results were not successful. At first it was felt that this was due to the type of rubber used for the hose. But with special hoses built from the type of rubber preferred for the technique, it was still impossible to obtain a bond strong enough to withstand the torque.

Another method available was 'Fusion Bonding'. In this process, a plastic end cap was extruded hot directly onto the hose. Again a bond was obtained but it was too weak for the job.

The final method which was investigated involved bonding a fitting to the hose during the curing of the hose. By using a suitable type of metal fitting, this process achieved a bond by molecular interaction between the rubber and the metal *. A number of successful

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* This is the principle used in the production of 'Metalastic' components.

fittings were obtained and tested to several hundred thousand cycles. However, the problem of scatter in cycling results again emerged and, in addition, the method restricted the production of hoses to single lengths rather than multiple lengths which could be subsequently cut. The latter method was desirable for production purposes because of its cost advantages.

At this point the progress with adhesive and bonding methods was examined by the team and the Product Development Director. Because of the unreliability of the results, it was decided that this line of research should end and attention be focussed instead on mechanical fittings. This is a good example of the sort of decision which often arises in development work. The team had devoted several months' work to the topic and there was still a chance of success. Each of the techniques described had expert supporters in the Research Centre and elsewhere in Dunlop. They, too, had worked hard to arrive at a solution to the problem. Nevertheless, limited resources of time and money meant that a judgement had to be made about which line of research was most likely to achieve success.

3. Mechanical Methods

Alongside the research into adhesive and bonding methods, there had been also a study of mechanical methods. These were the 'swaged' or 'crimped' types of hose end-fittings which are used extensively by Dunlop and other companies for high pressure hoses. These fittings consist of a plug inside the hose and an outer ring whose diameter is reduced either by hydraulic pressure operating through dies or by repeated mechanical impacts. These designs were not favoured by the team on two counts - the fittings were cumbersome and special equipment was required for their assembly.

Typically, the length of a standard swaged fitting was twice the diameter of the hose. From the marketing information, it was clear that the overall length of the hose had to be kept as short as possible. It was decided that the length of any fitting must not be greater than approximately 0.75 x diameter of the hose. If this was exceeded, the overall length of the eventual T.H.A. would be uncompetitive. The equipment required for assembly of the fitting on the hose would be simple and quite cheap for sizes up to about 50 mm diameter, but above this size, a hydraulic press of several hundred tonnes capacity would be required to assemble the fittings.

In addition to these problems, experts consulted within Dunlop advised that existing designs had been produced to cope with high pressure but not torque. With these problems in mind the team considered novel designs. One design, which became known as the 'compression fitting' was extensively developed and tested. It is shown in Fig. 4.14. Although the fitting was eventually abandoned because of unsatisfactory performance, details are now given of the development programme since they highlight several important features of working with rubber.

After the design idea had been proposed, calculations were made to find the stress levels in the fitting before a series of practical tests was started. The absence of published information on stress/strain relationships for rubber made a complete analysis of the fitting impossible in the time available. The writer found that comparative information for rubber was not readily available from the Research Centre or other sources. He discovered that the properties of the many different types of rubber compounds vary greatly and that a quantity such as the compression modulus which relates stress and strain can vary greatly for a particular compound, depending on the shape of the sample tested.

The calculation did produce information about the tension in the bolt and the tightening torque required on the nut. A fitting for a 50 mm diameter hose was produced with a 10^{o} taper angle. This was tested with air pressure up to 6 bar without failure. Next, it was decided to check the effects of other taper angles,

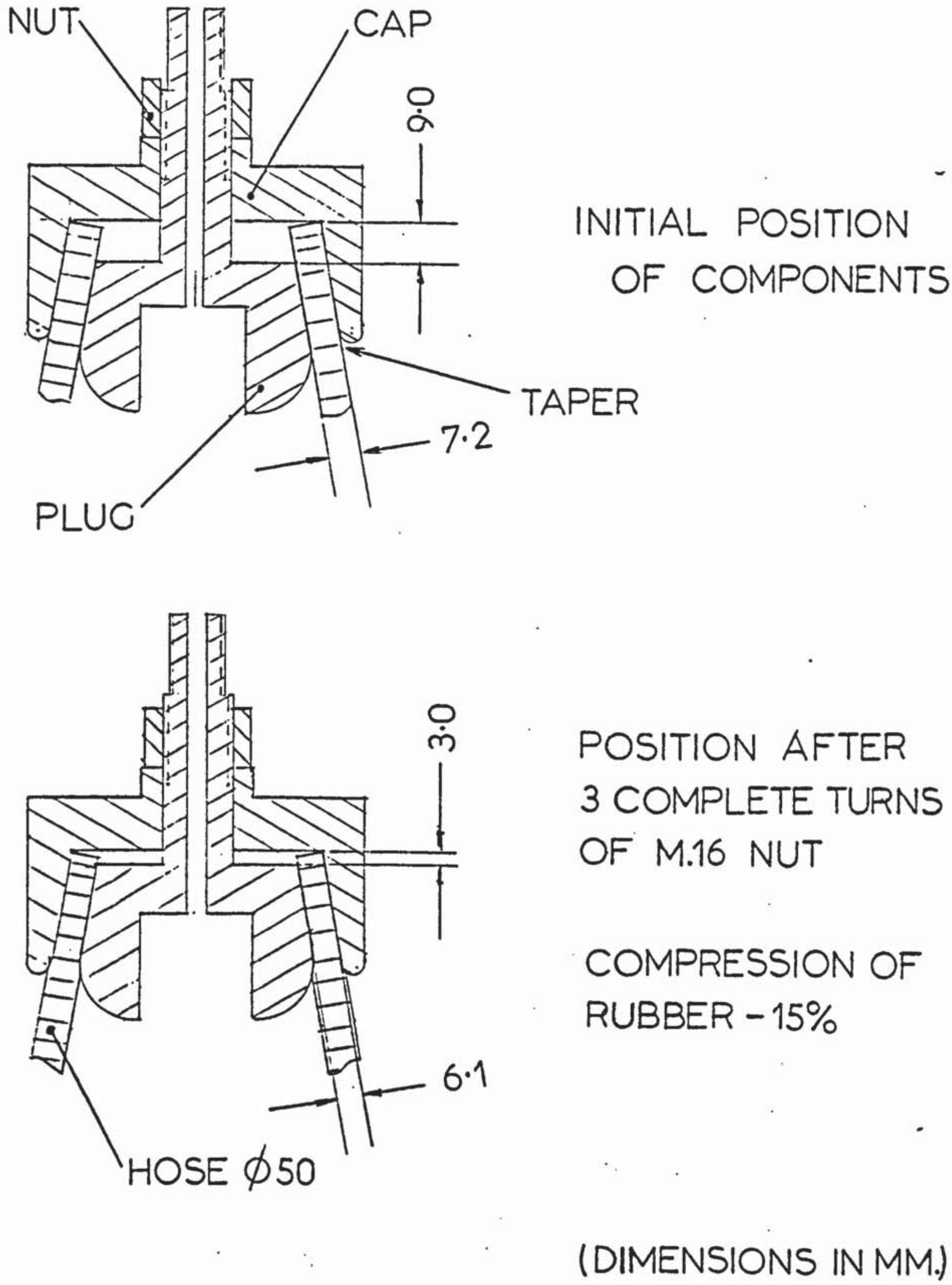
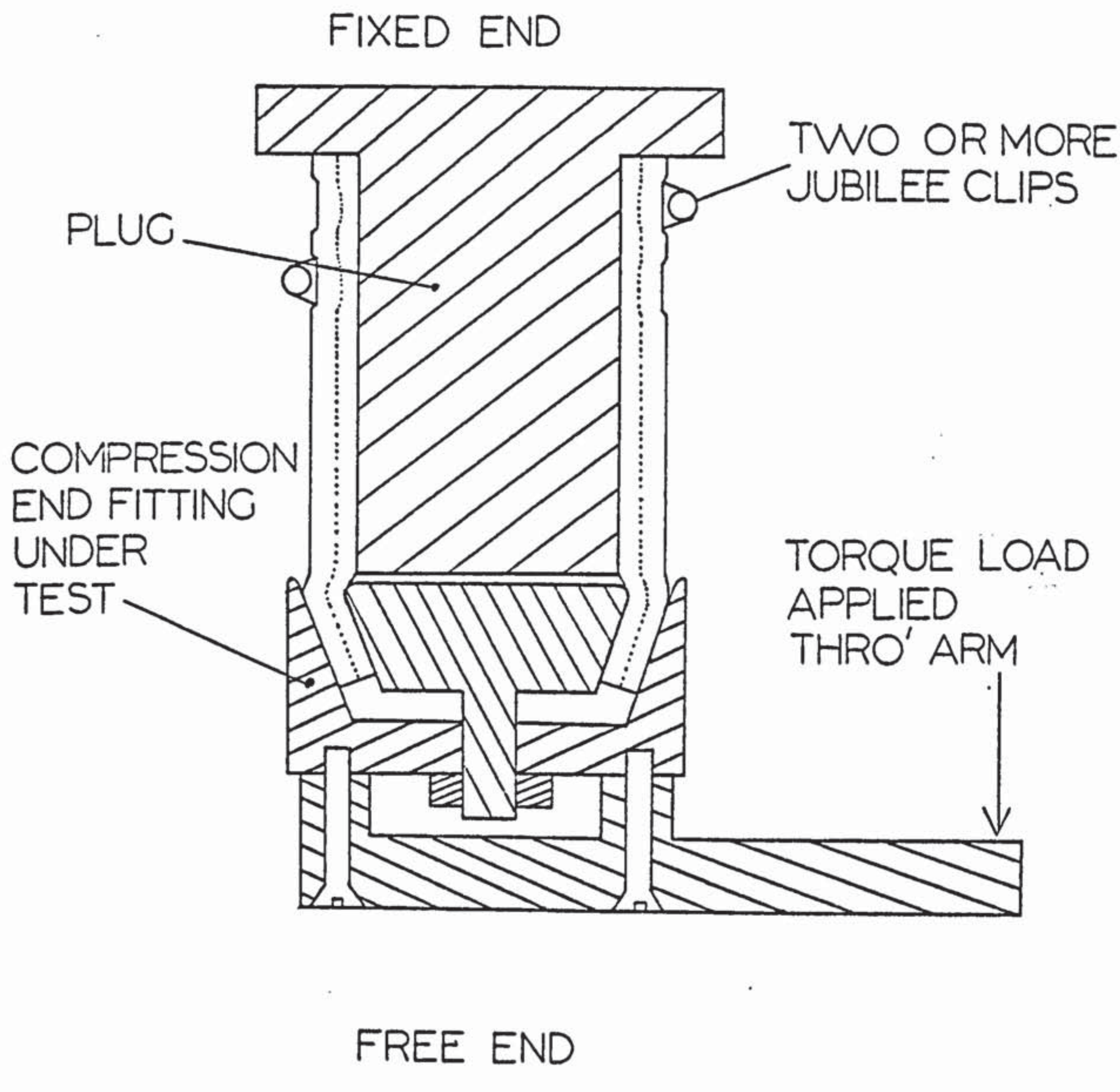


FIG. 4.14: SKETCH SHOWING SECTION THROUGH COMPRESSION TYPE END FITTING.

i.e., 5°, 15° and 25° and also the effects of overload pressure/torque outputs to give the factor of safety with each fitting. Since 6 bar was the maximum air pressure available in the factory it was decided that the fittings would be tested by loading with weights at the end of an arm. That is, a torque would be applied to the fitting which would thus be trying to twist itself away from the fixed hose. This method required as short a hose as possible so that it would not buckle as the torque was applied. A 'free' hose length of 5 to 10 mm was found to be satisfactory, if supported internally by a plug as shown in Fig. 4.15.

Each of the four fittings was then tested again with air pressure up to 6 bar using the normal testing arrangement. Both sets of results are shown in Fig. 4.16. Although none of the fittings failed at 6 bar it can be seen that the trends in the curves are distinctly different from the non-pressure test results. The team concluded that the non-pressure test was not a valid simulation. A high pressure hydraulic pump was obtained so that fluid pressure tests could be carried out above 6 bar. The fittings were found to slip at 8 to 10 bar. Similarly non-pressure and high pressure tests were conducted on a 100 mm end-fitting. The dissimilarity of the results is shown clearly in Fig. 4.17.

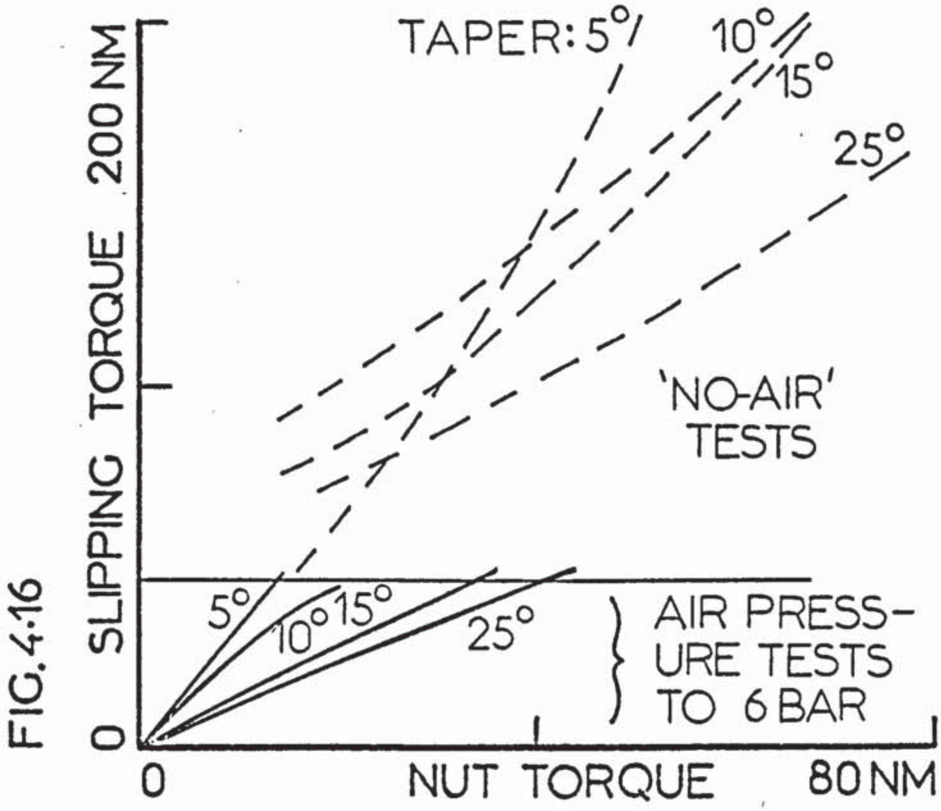
Failure at pressures of 8 to 10 bar meant that the method was no better than the Jubilee clip method - the 2:1 safety factor was not being achieved. Tests on fittings with different surface treatments - several



SECTIONAL VIEW FROM ABOVE

FIG. 4·15: 'NO-AIR' TEST ARRANGEMENT FOR COMPRESSION END FITTINGS.

ALL HOSES TESTED AT ZERO ROTATION.



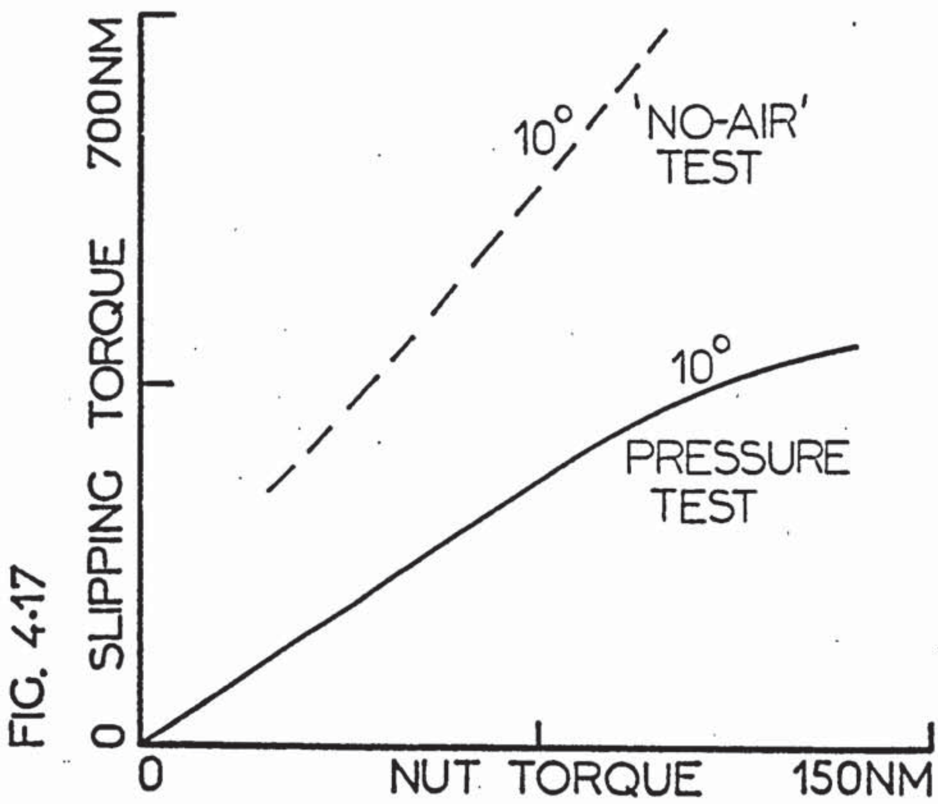


FIG. 4·16: GRAPH OF SLIPPING PRESSURE/TORQUE V. NUT TORQUE FOR 50MM DIA HOSES.

FIG. 4·17: GRAPH OF SLIPPING PRESSURE/TORQUE V. NUT TORQUE FOR 100MM DIA HOSES.

grades of shot blasted finish and a knurled finish were tried - did not result in better performance. Very high tightening torques on the fixing nuts (e.g., 150 Nm on 100 mm size) were already being used. Higher torques could have overstressed the bolts and, certainly on 100 mm sizes of hose and above, would have been extremely difficult to apply with manual equipment. Once again a line of research had to be abandoned.

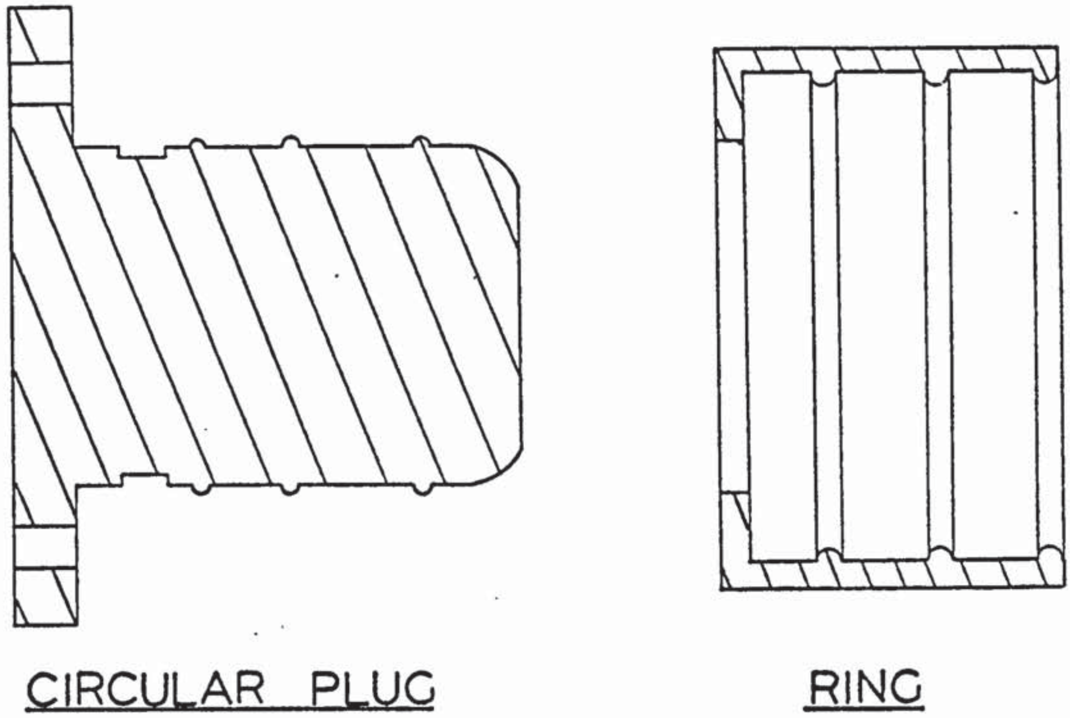
For the writer and his colleagues there was an important lesson : the need to test substitute procedures most carefully. In this case, the use of non-pressure tests had given erroneous results which might have led to serious problems at a later stage if blindly accepted. The initial reasoning had been wrong : fixing the hose and applying a torque to the fitting did not simulate the pressurising of a hose to produce an output torque. An effect of the behaviour of rubber had been overlooked : that during a pressure test, the diameter of the hose increases, the wall thickness decreases and the rubber tends to flow out of the fitting. During the non-pressure test, the application of the torque load hardly affects the diameter or the wall thickness. In fact, depending on the orientation of the reinforcing cords some thickening of the wall could occur which would assist the functioning of the end-fitting.

The team now turned their attention once again to swaged fittings. Recent marketing information had suggested that the larger, 100 mm diameter hoses would not be required - 75 mm would be the likely maximum size. This information meant that swaged end-fittings were now an attractive possibility. Hydraulic presses were available in Dunlop which could probably cope with these sizes, especially if the length of the fittings could be successfully reduced.

At a meeting with experts from the Hydraulic Hose Division of Dunlop, standard designs of end-fittings were carefully examined. As a result, a general design for the Torque Hose was derived as shown in Fig. 4.18. It has been mentioned already that it was essential to restrict the length of the fitting to ensure a compact product. Hence, the design in Fig. 4.18 was built in three lengths - 0.5x, 0.75x and 1.0x nominal diameter of hose. Once again, 50 mm diameter hoses were used in tests which were started during February 1976.

As with the other types of fitting, the initial testing subjected the hose and fitting to a pressure of 11 bar - twice the normal working value. The shortest fitting failed this test, but the 0.75x diameter size proved satisfactory. The test on this size was successfully repeated three times, each fitting being attached to the hose using dies and a 60 tonne hydraulic press provided by Aviation Division at Engineering Group. The reduction in diameter of the ring during swaging was approximately 6%.

Four similar end-fittings were then tested on cycling rigs as part of experiments which were being



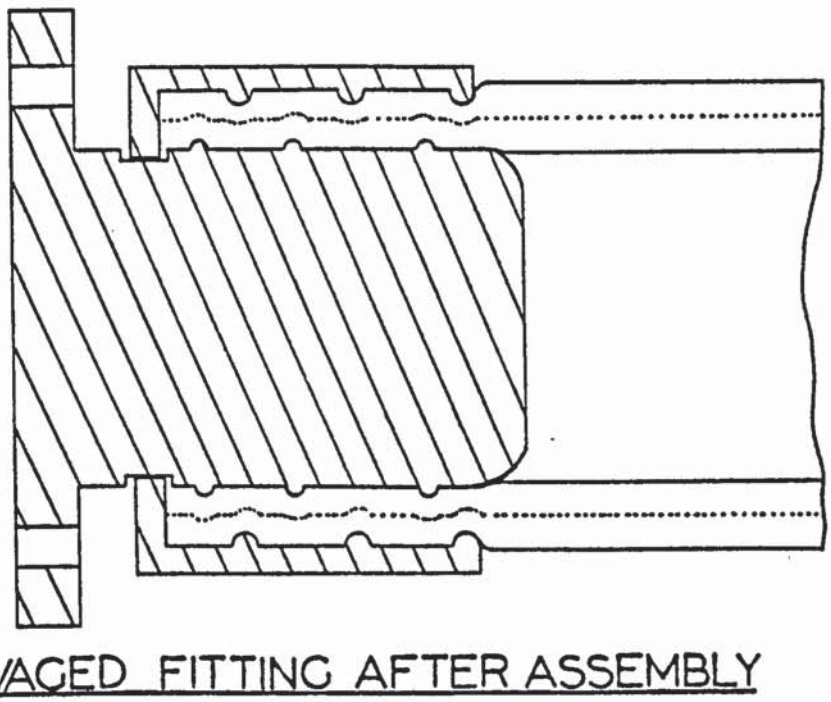


FIG. 4·18: SKETCH OF SWAGED END-FITTING.

carried out to check the fatigue lives of the hoses. In every case, failure of the hose by bursting occurred first. Even as the life of the hoses was increased (see next section) to 250,000 and then 500,000 cycles, the swaged fittings showed no sign of fatigue.

Thus, a hose fitting had been found which could withstand the pressure and torque loadings at twice the normal maximum level and had a working life which at least matched that of the hose itself. The next step was to confirm the results for hoses larger than 50 mm diameter. It was planned that this should be done on delivery of larger diameter test hoses which had been ordered from a small Dunlop subsidiary. These hoses were planned as samples of the 'production' hose to be made by the subsidiary to the specification developed by Research Centre and the writer. Unfortunately, although more than six months elapsed, the hoses had not been delivered when the writer ceased full-time work on the project in March 1978.

The performance of the 50 mm size suggests to the writer that satisfactory results will be obtained for sizes up to 75 mm diameter. However, full tests must be carried out on larger hoses before production models of the actuator are built. The delay in the supply of these hoses highlights several points :

1. A development programme can be seriously disrupted by an underestimation of the delivery time for materials and equipment.

2. Communication and co-operation between different divisions of a large company may be ineffective. In this case, negotiation at even the highest level failed to improve the supply of test hoses.

3. Enterprises wishing to develop new business must respond punctually to customers' requests. The subsidiary claimed to be keen to participate in the Torque Hose business by becoming the supplier of the hoses for production. However, its lack of dynamism caused the writer to suggest the use of another supplier - if necessary, one outside the Company.

The effect of constraints was experienced most sharply during this phase of the development work. The constraint on size has been highlighted already - the device had to be compact and this eliminated some potential solutions to technical problems. Another major constraint was that of cost ; the Business Plan for the project had shown that production of the Torque Hose Actuator could be profitable only as long as costs were within limits. These limits had been defined by analysis of the prices of competitors' products and by estimation of costs of proposed T.H.A. designs. Some costs, e.g. of the hose itself and of the casing, appeared to offer little scope for reduction. Other costs, such as the end-fitting had to be contained within the balance which made up the total maximum production cost. Constant awareness of the need to limit costs during the investigation of end-fixing methods, resulted in a reluctance to investigate expensive solutions (which might have been subsequently modified to make them cheaper) but ensured that the commercial acceptability of the product remained the over-riding priority.

4.5 Examination of Hose Fatigue Life Problem

The testing of a prototype actuator in March 1977 and other cycling tests had revealed a serious problem - the life of the hose was found to be unacceptably short. Instead of at least 250,000 cycles for a 50 mm diameter, 155 mm long hose working through 90^{o}, values as low as 50,000 had been recorded. The consequence of this for the viability of the proposed new product was considered so great that the project was almost closed. Expectations of early commercial success for the project had been running so high that this set-back was viewed with great concern. The writer was given two months (later extended) to show that the life of the hose could be improved and that the project should continue.

The first step in this work was a review of action taken to extend the fatigue life during the earliest work at the Research Centre. A number of changes had been adopted which gave minor improvement in life although none had been tested in isolation. However, the use of a rigid sleeve to restrict the amount of dilation of the hose had clearly greatly improved the life. It seemed likely that this could solve the present problem but the writer was reluctant to adopt the solution because it would cause a reduction in torque output of as much as 50%. To counteract this a larger diameter of hose would be needed - which would lead to a general increase in dimensions when the aim was to produce a compact product.

1. Information on Tensile Fatigue Life of Rubber

The writer examined published work on the relationship between strain and fatigue life for rubber. With knowledge of the relationships involved he hoped to be able to devise a method of increasing the life of the hose by reducing the strain in the rubber. Work reported by Lake (74) gave information about tensile fatigue life for various rubbers including natural rubber and neoprene, the main constituents of the Torque Hose. From the graphs presented, the following trends could be seen :

Rubber Strain*	Cycles to Failure
100%	100,000 to 500,000
200%	10,000 to 100,000

Earlier work on the Torque Hose had shown that when the diameter increased by half, the corresponding strain in the rubber between the cords in the hose wall was more than 100% (57). Similarly with a doubling of the diameter on pressurisation, the rubber strain was over 200%.

It was interesting to relate Lake's information to the poor fatigue results being obtained at Coventry, i.e.,

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* In rubber engineering, strain is commonly written as a percentage rather than as a ratio.

Approx. Rubber Strain	Cycles to Failure
100%	Approx. 250,000
200%	80,000 to 100,000

These fatigue results were clearly as good as could be expected at the strain levels being employed. If strain levels of, say, 75% could be achieved, then Lake's work showed that an increase in life (to 1,000,000+ cycles) could occur. One method of reducing strain would be to reduce the number of cords in the hose whilst keeping the dimensions the same. In this way the proportion of rubber to inextensible steel cord would increase and the rubber strain would reduce if the dilation on pressurisation remained the same.

The idea was presented in a report (75) which was distributed to the Product Development Director and members of the Research Centre. The argument was well received and it was suggested that a number of hoses should be built to enable the theory to be tested. The major objection to the idea concerned the availability of steel cord preparation for manufacturing the hose. Until then, a standard preparation had been used. If a non-standard cord spacing was adopted, a production hose would have to be built using a winding process to lay the cords. This might not be expensive nor difficult but it was a departure from the method used for building test hoses to date. For this series of tests it was agreed that a number of cord preparations with non-standard spacings would be specially manufactured and the hoses built in the normal manner.

During operation of the Torque Hose the tension in each cord with the existing spacing (98.5 cords per 100 mm) was very small but would increase as the number of cords was reduced. The minimum number of cords for safety was calculated and found to be 40 cords per 100 mm. Together with more precise information about the anticipated fatigue life improvement, this calculation was included in a report issued by the writer (76).

2. Tests on Hoses with Different Cord Spacings.

Results from these tests were discussed in reports issued in Dunlop on 18th August 1977 (77) and 19th September 1977 (78). The first hoses to be tested had constructions of 98.5 cords per 100 mm (standard hose), 104 cords per 100 mm and 64 cords per 100 mm. Each was cycled to failure on an "end load rig" as shown in Fig. 4.12 which allowed 90^{o} of rotation of the free end before full torque developed against a stop. The hoses were 165 mm * long with cords lying at a diameter of 50 mm and were free to dilate without restriction. Air pressure of 5.5 bar was used. The results are shown in Fig. 4.19 and discussed in the Appendices which contain copies of references [75 - 78].

Fig. 4.19 Results of First Test on Hoses with Different Cord Spacing

Hose number	68	75	78
Cords/100 mm	98.5 (std.)	104	64
Cycles to failure	51,326	8,400	15,626
Maximum torque	43 Nm	51 Nm	53 Nm
Maximum increase in Diameter	54%	65%	72%

* Free working length between end fixings - overall length 200 mm.

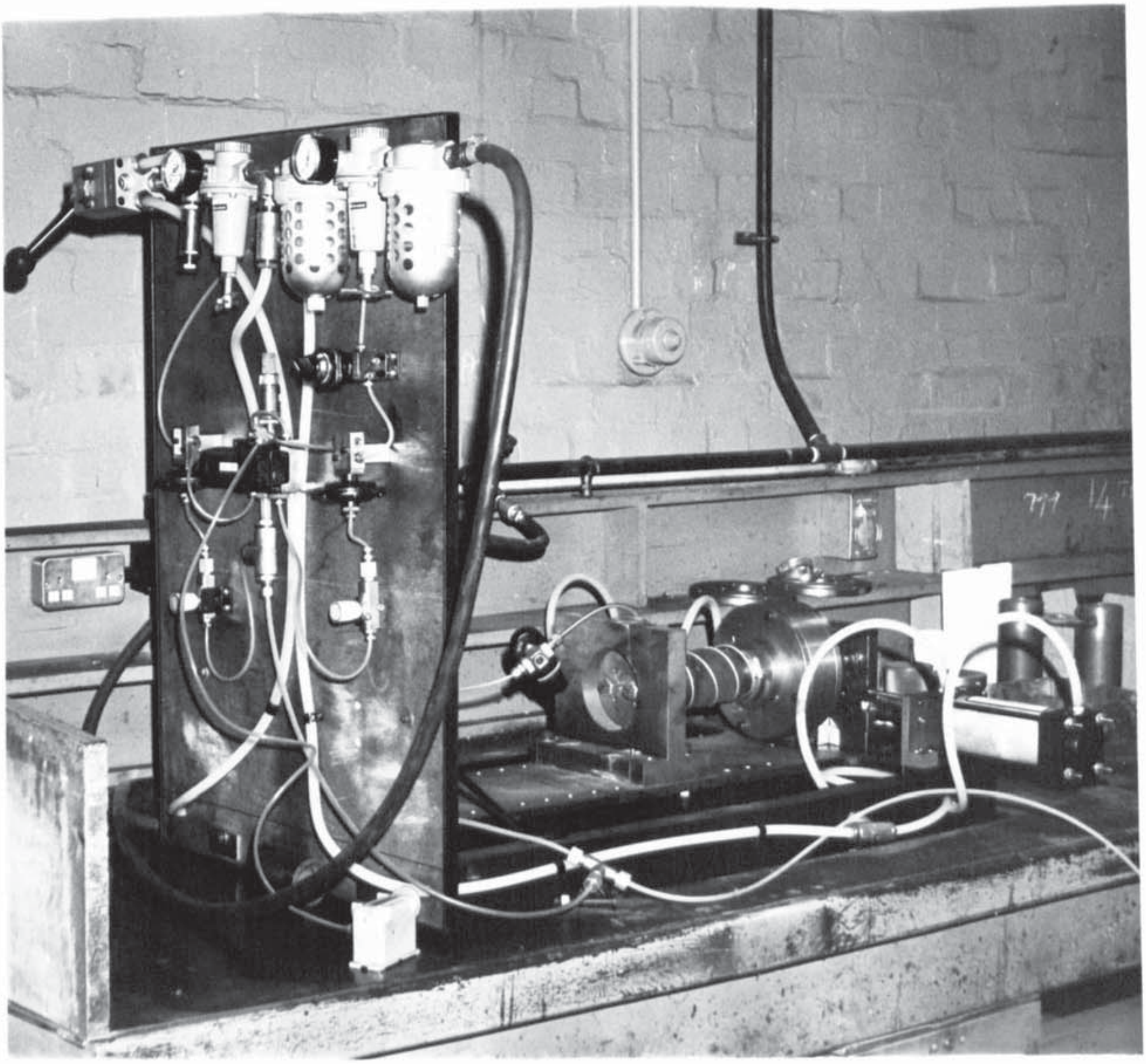

Fig 4.20A   General View of 'Constant Load'

Hose Test Rig

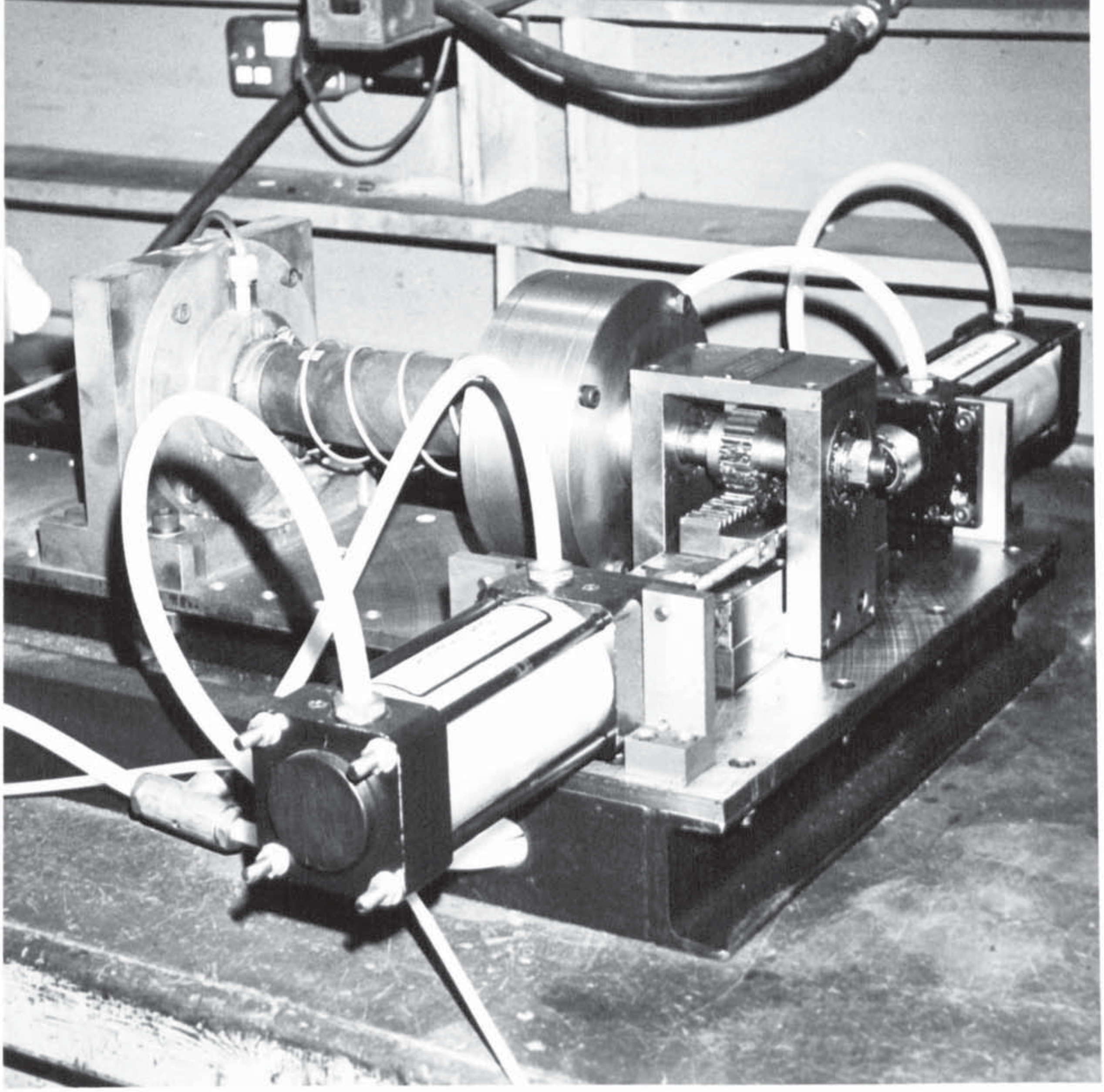

Fig 4.20B Close up View of 'Constant Load' Hose Test Rig

would help to ensure a uniform high-quality hose and minimise the 'scatter' of results generally experienced with rubber. The main alterations were :

1. Instead of a single, thicker layer, hoses were built using several overlapping thin layers of rubber on each side of the cord layer. Hence, the butt joins would be staggered and would not extend completely through the cover (outer layer) or liner (inner layer). See Fig. 4.21 below.

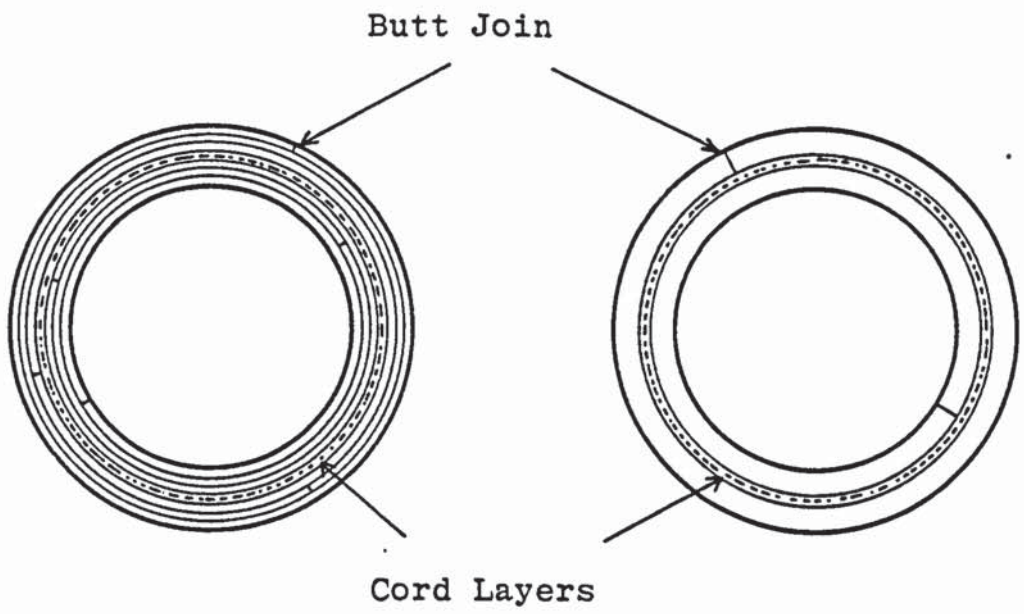

Fig. 4.21 Revised and Original Construction of Torque Hoses

During curing, all joins should fuse and disappear but sometimes consolidation was not 100%. It was considered that this method would give better integrity of construction.

2. The layer of the liner adjacent to the cord layer was replaced by a different type of rubber from that used in the rest of the hose. The reason for this was to provide a modulus gradient between the main rubber of the hose and the special rubber used in the cord layer preparation. A single rubber could not be used throughout because rubbers which bond to steel cords do not have physical properties suitable for the bulk of the hose, e.g., ozone resistance.

3. Hoses were cured with an internal pressure of 28 bar instead of 11 bar to improve the consolidation of the hose wall. Also the cure time was set at 45 minutes instead of 60 minutes as used previously. Recent work at the Research Centre had shown that excessive cure times could lead to reduced physical properties of the rubber.

The results of the fatigue tests on these hoses were shown in the form of a graph of cycles to failure against cord spacing (see Appendix 4). This indicated that the best life was obtained with a spacing of 80 cords/100 mm but that an acceptable life was also obtained with the standard hose spacing of 98.5 cords/100 mm. Since the target life was 500,000 cycles, the results suggested that any spacing in the range 80 - 100 cords/100 mm would be satisfactory if the dilation was restricted to 30%. Hence, it was decided to retain the standard hose, the basis of which was an inexpensive mass produced cord preparation ; although, if an alternative method of hose manufacture were adopted later, a move to 80 end/100 mm could be made. To counteract the side effects of the restrictor, i.e. the reduction in torque, it was proposed that a larger diameter of hose should be used.

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3. Further fatigue testing

The writer felt that further tests were required on hoses with different cord spacings even though it had now been decided to use the standard hose. His reasons were :

1. For most cord spacings only a single result had been obtained. Some indication of the repeatability of results was needed. Where two similar hoses had been tested (104 cords/100 mm) the life of one was almost twice that of the other.

2. It was considered that information about the cycling performance of these hoses would be of value to designers of other reinforced rubber items subject to cycling loads. Discussions with other researchers and an examination of technical literature confirmed this view.

The writer's supervisors agreed with this proposal and another nine hoses were made - 3 each at 64 cords, 80 cords and 98.5 cords/100 mm. These hoses were tested during the period October 1977 to February 1978. Fig. 4.22 is a graph of cycles to failure against cord spacing for all results obtained during the test programme. Although the scatter of results is marked, the trend identified earlier is confirmed : optimum fatigue life is obtained with a spacing of approximately 80 cords/100 mm. This information will be of value when further work is undertaken on Torque Hoses, if alternative methods of hose construction are available. These results suggest that similar relationships probably exist in other types of rubber structures which are reinforced with cords and are subject to cycling loads.

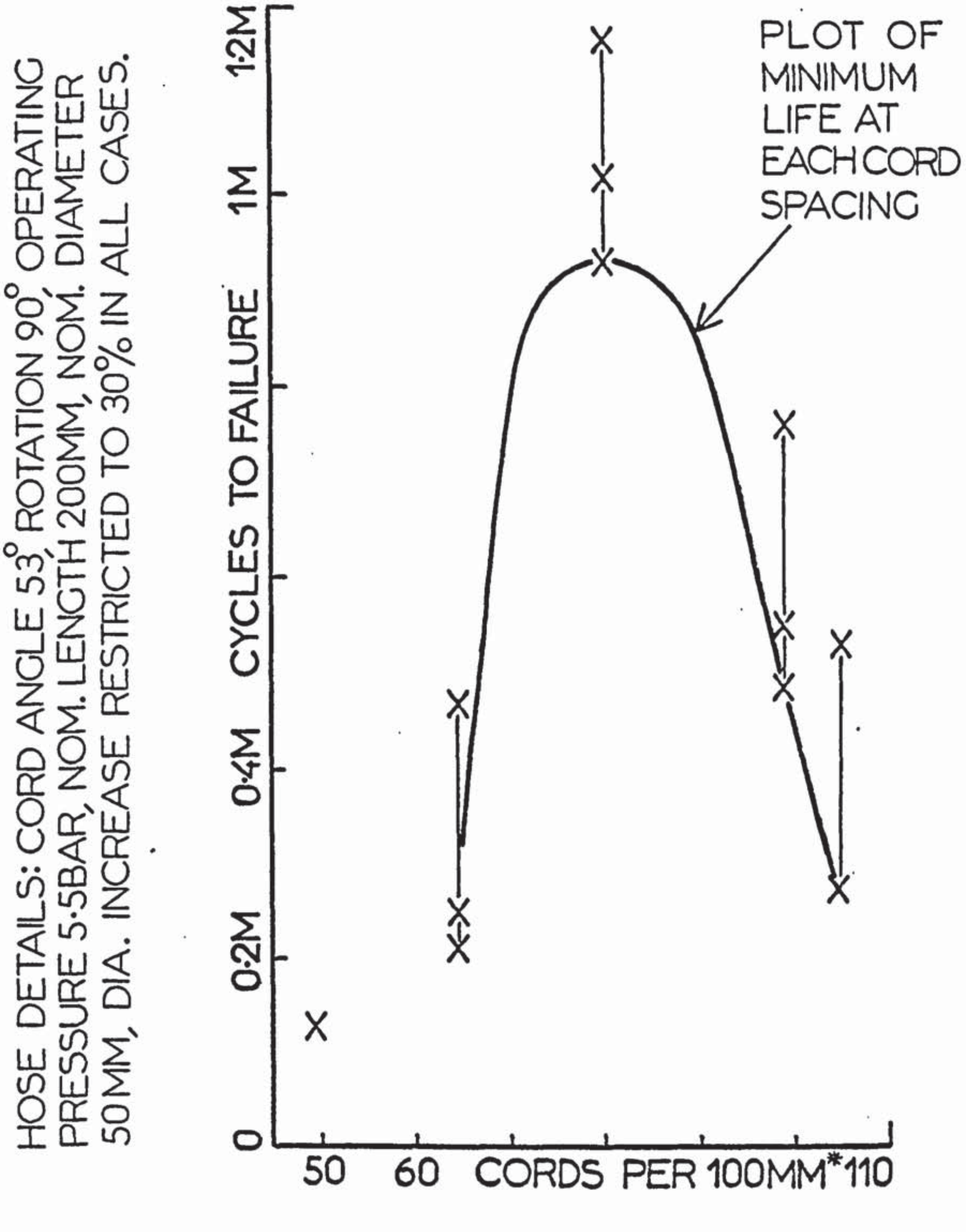

FIG. 4·22: GRAPH OF FATIGUE LIFE V. CORD SPACING SHOWING OPTIMUM SPACING APPROX. 80 CORDS PER 100MM.*
(*MEASURED AT 90° TO THE CORD DIRECTION)

CHAPTER 5

MARKETING ASPECTS OF THE STUDY

5.1 Introduction

When the project was allocated to the writer in October 1975, it had been a development project in P.D.U. for about 2 years. Previously, it had existed for about 18 months as part of a project at the Research Centre, although work had not been continuous at either location. There was no evidence that any formal marketing work was carried out prior to October 1975 although strategies were decided upon, indicating that some informal marketing procedures at least had been used.

It soon became clear to the writer that an analysis was required of the nature and value of the market for pneumatic actuators.

As already reported, the project was subject to several changes of circumstance and policy. The completion of the 'desk research' phase of this marketing work coincided with a management review of the project. After presenting the information obtained, a go-ahead decision was taken - although non-marketing factors were also involved.

Other lines of marketing work were also pursued. Originally it had been considered that the device should be developed to satisfy specific applications. To identify suitable applications, a design competition was considered. For the same reason - but also to assist in acquiring an understanding of pneumatic devices and their uses - exhibitions were visited. In addition, meetings were arranged with companies and individuals, known to be working in this field. To help with presentations, a portable demonstration unit was designed and built.

Analysis of the data from from secondary sources left several marketing questions unanswered and led to a decision to undertake some practical research. After a study of market research methods, and of the areas to be examined, it was decided that a questionnaire approach would be the most valuable. A pilot run in Dunlop Divisions produced some information, but several factors caused the main work to be abandoned.

One of these factors was a decision to eventually distribute the product through one or both of two control euqipment suppliers. It was decided that a product evaluation would be based on marketing information provided by these companies, the theory being that they were experts in their field and would offer better quality information than could be discovered otherwise. This decision had profound effects on the project.

5.2 Marketing Work Prior to October 1975

Reference to Chapter 6 shows that the organisation of P.D.U. did not include a marketing specialist. Two main reasons for this were :-

1. Engineering Group itself had no formal marketing section. By and large, its products were supplied to a small number of large purchasers, i.e., Aviation Division products to Ministry of Defence and aircraft manufacturers, Wheel Division and Suspension Division to vehicle manufacturers, Plant & Equipment Division products to tyre manufacturers. The controlling body of Directors and Senior Managers was dominated by production specialists - balanced only by the Director of P.D.U., the Group Comptroller and the Personnel Director. There was no Marketing Director.

2. In creating P.D.U. the intention had been to give its Director freedom of discretion in the selection and development of new products. It was considered that P.D.U. should be a 'new product generating factory' and that the wide experience and range of contacts of the Director would ensure that profitable projects were selected for development, i.e., that assessment of market potential would be carried out by the Director. However, the Director was essentially an engineer and as a result, P.D.U. consisted of highly inventive engineers whose main concern was with the technical aspects of their projects.

It seems that new projects originated in one of two ways in P.D.U. Either the Director recognized a need for a new product and set about making preliminary designs or a new invention would be offered to the unit for development into a product.

The Torque Hose came into the second category, having been passed to P.D.U. by the Research Centre. A number of possible uses were suggested, including vehicle engine throttle control and automatic opening of greenhouse windows (by filling the hose with a liquid having a high thermal expansion it would react to temperature changes by rotating). However, it was decided that at the time, the best potential lay in the development of the Torque Hose as a 'bus door actuator.

At this time, (summer 1973), P.D.U. was already working on a device which could be sold to a major vehicle manufacturer for use on a new 'bus. There had been problems with this original device and development had to be abandoned. The Torque Hose offered another means of doing the job and a development programme was set up in collaboration with the Research Centre. The project was eventually discontinued in 1974 when it was found through fatigue tests that the required operational life of 10^6 cycles could not be achieved.

It had been anticipated that this bus door application would have been the first of several specific uses for the Torque Hose. Even so, it is interesting that no formal market assessment was carried out, for in retrospect it is probable that if the technical problems had been solved, the 'bus door application would have failed commercially because :-

1. The selling price which the customer would have accepted would have been too low in relation to the production costs.

2. Sales would have been too small to justify setting up production in Engineering Group. Subsequent marketing work (see next section) showed that the total market for pneumatic actuators was relatively small, so individual segments (such as actuators for 'bus doors) were not likely to yield high enough volumes of business.

The Torque Hose remained in P.D.U. after this exercise, and occasional work was done as ideas for its use were conceived. Nothing came of this, but during 1975 the Director showed the device to a distributor of valves and pneumatic equipment. This businessman was intrigued by the concept and thought that if it could be developed to operate ball valves, then there would be a good market for it. It was agreed that a technical specification would be drawn up and a prototype built and tested.

By October 1975 the prototype was being completed but the businessman did not return - and the contact was never re-established. At this point it was difficult to justify further work on the device, but the Director was still convinced of its potential.

Consequently, it was decided to invite the I.H.D. Scheme to allocate the project to a Ph.D student.

5.3 Use of Competition to Identify Product Application

In the early days of the writer's association with the project, before a more systematic marketing approach had been developed, a number of ways were considered of identifying specific applications for the actuator. One possibility was to organize a design competition through the monthly Dunlop newspaper or a generally-available technical journal. The idea received some support in Dunlop and it was decided to seek information about the effectiveness of design competitions.

Some months earlier, Dunlop Head Office had run a competition as part of a corporate advertising campaign. Advertisements listed some of the many products sold by the company and then invited the reader to design another one. First prize was £1,000.

Dunlop's General Advertising Manager was contacted to find out about the success of the competition. He said that it had essentially been a corporate advertising exercise and although over 900 entries were received, no potential new products had emerged. There had been some problems with the competition. A few entrants who did not win claimed that Dunlop was stealing their ideas ; a situation which could have become very embarassing for the Company. Another consideration was that it was difficult to justify awarding cash prizes for inventions when employees were expected to produce ideas in the normal course of their jobs. Generally, the Advertising Manager did not think a competition was an effective way of generating new product ideas.

The Dunlop competition had been run in the National Press and it was thought that it would be useful to find out about results obtained from a competition aimed at a specifically technical readership.

Linear Motors Limited had recently sponsored a competition in "Design Engineering" (79). Like the Torque Hose, the linear motor was clearly a product looking for applications. The copy of the competition advertisement said :-

"Instead of brilliant novel 'breakthroughs' of limited application we'd rather you concentrated your talents on redesigning commonplace objects. To open up ready made volume production uses for our product that no-one else has thought of."

Linear Motors Limited was contacted and the organizer of the competition, the Sales and Marketing Manager, agreed to give information about the results obtained.

The idea of the competition had come from the Managing Director of the parent company. The objects of the exercise were :-

1. To educate industry to consider using linear motors in place of less efficient conventional motors.
2. To identify new applications. Although Linear Motors Limited had been in existence a few

years, no outstanding applications had been found.

A measure of success was achieved in the case of the first objective. 1,400 enquiries were received, approximately 50% seeking information and 50% requesting entry forms for the competition. For the total cost involved (about £4,000) which included fees, prizes and expenses, it was considered that the advertising was very effective.

However, the second objective was not satisfactorily achieved. Only 34 entries were received and none was of useful quality.

The Sales and Marketing Manager's conclusions were that :-

1. Competitions are only suitable for established products seeking further applications.
2. Such activities should be seen primarily as advertising exercises and not be expected to provide important new application ideas.

In the light of these reports on the Dunlop and Linear Motors competitions it was concluded that a design competition for the Torque Hose would not be helpful. Furthermore, in the course of checking with departments in Dunlop which might have had an interest in the Torque Hose, the Patents Department had indicated reservations about going ahead since the publicity might jeopardise the patent on the Torque Hose which had not then been published.

5.4 Data From Secondary Sources

This work took place during the period from November 1975 to September 1976 with subsequent revisions and additions. There were two main aspects to the study.

- Identification of companies selling pneumatic actuators. Comparisons of technical performance, size, price, etc.
- Estimation of the value of the total market for pneumatic actuators.

1. Product Comparison

A preliminary examination of pneumatic equipment at exhibitions suggested that manufacturers tended to produce standard ranges of rotary and linear actuators, i.e., that they did not usually produce special types for specific applications. In fact, in the case already mentioned, of the actuator for the 'bus door, the product eventually chosen was an 'off-the-shelf' rotary actuator.

Since the Torque Hose was a rotary actuator it was decided to seek information about this type of product as supplied by various companies.

The first step was to obtain a list of all companies operating in the market. This was drawn up by reference to :-

(i) Trade Association

For pneumatic equipment the relevant one is the British Compressed Air Society. A request to it for information brought a copy of the 1975 annual report which contained a list of member companies and their major products. 51 firms were listed, of which 12 sold pneumatic control equipment. The list included most major suppliers but, interestingly, did not feature the two companies later identified as the most important manufacturers of rotary actuators.

(ii) Buyers' Handbooks

One found particularly useful was part of a series published by Technical Indexes Ltd. (80). This indicated that some of the firms already noted did not supply rotary actuators, but it also provided some additional firms.

(iii) Trade Directories, e.g., Kompass, Dun & Bradstreet

These were useful as a check that the list was comprehensive and also gave information about company size and turnover. (See Fig. 5.1 for list of companies).

Further visits to exhibitions confirmed that all the major companies selling rotary actuators had been identified. With an idea of which companies were in the market, the library of manufacturers catalogues at Engineering Group was consulted. From these much technical information was obtained and it was possible to categorize different models of rotary actuators.

Fig. 5.1

Firms Supplying Pneumatic Control Equipment in the U.K.

Atlas Cooper (G.B.) Limited
Austin Beech Limited
Bellows International Limited
Bradford Cylinders Limited
Carter Controls U.K. Limited
Compair Maxam Limited
Delta Fluid Power Limited
Exhardt Limited
Enots Limited
E.P.H. Actuators Limited
Festo-Pneumatic Limited
Hymatic Engineering Limited
Kinetrol Limited
Kuhnke Limited
Leibfried (U.K.) Limited
Martonair Limited
Matryx Limited
Mead Fluid Dynamics Limited
Mecdine Limited
Mecman Limited
Minair Limited
Norbro Pneumatics Limited
C.A. Norgren Limited
A. Schrader's Son
Serck Controls Limited
Spirax-Sarco Limited
Telektron Limited
Truflo Limited

Inevitably, not all the information required was available, particularly about selling prices. Hence, it was necessary to contact most of the firms. A telephone call was satisfactory in cases where the range was small and the information required quite straightforward, e.g., up-to-date prices. For more detailed information, it was usually necessary to write to the firm concerned.

It was interesting to note the different responses to these enquiries. Out of 12 companies the average time to reply was 3 weeks although some responded by return. One company did not reply and another sent a letter 2 months later. Half the replies did not answer the points asked but enclosed sales leaflets - many suggesting contacting the sender for further details! The point of this digression is to show how difficult it can be for a designer to obtain specific information about alternative products.

By now, a list of features to be compared could be drawn up. The list eventually comprised of :-

Torque Output

Selling Price

Dimensions

Operating Principle, i.e.,
piston, vane, etc.

Degrees of Rotation offered, e.g.,
90°, 180°, etc.

A basic division of actuators was apparent, namely 'double-acting' types where operation was powered by air in both directions of operation and 'single-acting spring return' where operation was powered in one direction but movement in the reverse direction was achieved by a spring. Consequently two comparison charts were drawn up (Fig. 5.2 and Fig. 5.3).

From these charts, common values of torque output were observed which most manufacturers supplied. To complete the survey, characteristics for the T.H.A. were estimated for these torque values on the basis of the technical work completed to date. Selling prices could not be estimated directly since no models yet existed but by drawing sketches of possible prototypes, very tentative cost prices were obtained.

A number of companies listed in Fig. 5.1 do not feature in the survey. The reasons for this were :-

i) Companies were found not to be producing rotary actuators.

ii) Companies had gone, or were going, out of business.

iii) Companies were selling actuators but in such small quantities that they were not serious operators in the market.

iv) Some companies sold actuators produced by someone else who also distributed them on a larger scale.

A number of important points emerged from this comparative analysis of actuators. Fig. 5.3 indicated that, as a single-acting device, the T.H.A. appeared to have

Fig. 5.2

Comparison of Double-Acting Pneumatic Actuators
(Compiled August 1976)

COMPANY	MODEL	TORQUE RATING AT 7 BAR (Nm)	SELLING PRICE (£)	TYPE	APPROXIMATE DIMENSIONS h x d x w (mm)	ROTATION AVAILABLE (Degrees)
BELLOWS INTERNATIONAL LTD.	B-461-15 25 35 45	6 17 52 170	56-72 87-95 108-118 155-174	All Cylinder/ Piston/ Rack & Pinion	65x65x150 - 300	All 90,180, 360
CARTER CONTROLS U.K. LTD.	4" bore 5" bore 6" bore 8" bore 10" bore 12" bore	110 190 280 510 810 1250	Reliable price information not available	All Cylinder/ Piston/ Scroll	125x125x275 - 550 165x165x275 185x185x275 235x235x275 290x290x275 350x350x275	All 100,190, 280,370
DYNA-QUIP/ NORGREN LTD.	AP 300 AP 1100	34 125	34 60	All Cylinder/ Piston/ Linkage	100x100x200 125x125x225	90 only
E.P.H. ACTUATORS LTD.	PA 10 PA 25 PA 50 PA 100 PA 210 PA 420 PA 750	12 25 73 150 230 450 880	31 34 49 61 92 138 214	All Cylinder/ Piston/ Scotch Yoke	75x75x175 75x75x225 125x125x250 125x125x325 175x175x375 175x175x450 225x225x525	90 only
KINETROL LTD.	A B C D E	6 50 170 550 1350	15 23 33 74 114	All Vane Type	50x75x75 100x125x125 150x175x175 250x300x300 275x350x350	90 only
MARTONAIR LTD.	M 506 M 507 M 508 M 597	40 180 360 550	24 57-65 74-83 143-167	*All Cylinder/ Piston/ Rack & Pinion (*See footnote)	100x100x250 200x200x375 225x200x375 250x250x600	**All 90,180, 270,360 (**See footnote)
MINAIR LTD.	ARM 44 ARM 64 ARM 92 ARM 114	16 44 125 230	22 80 150 200 (all approx.)	All Cylinder/ Piston/ Linkage	85x85x225 - 375 100x100x225 - 475 150x150x325 - 625 175x175x425 - 800	All 90,180, 270,360
NORBRO PNEUMATICS LTD.	4001A 4002A 4003A 4003.5A 4004A	40 110 380 900 1475	29 48 96 143 200	All Cylinder/ Piston/ Rack & Pinion	100x100x150 125x125x200 175x175x275 225x225x350 250x250x375	90 only
SCHRADER	2¼" bore 4" bore	35 210	43-50 69-86	All Cylinder/ Piston/ Rack & Pinion	100x100x290 - 525 175x175x400 - 825	All 90,180, 270,360
TORQUE HOSE ACTUATOR	1 2 3	20 50 200	35 60 100	All Torque Hose	250x100x200 300x125x250 400x175x350	90 but greater possible with increase in 'h' dimension

NOTE :- *All except Model M 506 - Cylinder/Piston/Linkage

**All except Model M 506 - 90° only

Fig. 5.3

Comparison of Single-Acting Spring Return Pneumatic Actuators
(Compiled August 1976)

COMPANY	MODEL	TORQUE RATING AT 7 BAR (Nm)	SELLING PRICE (£)	TYPE	APPROXIMATE DIMENSIONS h x d x w (mm)	ROTATION AVAILABLE (Degrees)
DYNA-QUIP/ NORGREN LTD.	AP3003 AP1100S	15 each way 35 each way	72 75	All Cylinder/ Piston/ Linkage	100x100x250 125x125x400	All 90 only
E.P.H. ACTUATORS LTD.	PAS 18 PAS 33 PAS 85 PAS110 PAS260	8 each way 20 each way 55 each way 68 each way 150 each way	53 75 114 134 201	All Cylinder/ Piston/ Scotch Yoke	75x75x325 125x125x400 125x125x475 175x175x525 175x175x625	All 90 only
KINETROL LTD.	A-SRC B-SRC C-SRC D-SRC E-SRC	3.1 each way 24 each way 82 each way 260 each way 620 each way	22 33 58 129 219	All Vane Type	100x75x75 150x150x150 225x200x200 425x200x200 400x425x425	All 90 only
NORBRO PNEUMATICS LTD.	4001B 4002B 4003B 4002.5B 4004B	Forward Return 12 5.4 40 25 130 73 310 180 370 310	41 67 122 181 243	All Cylinder/ Piston/ Rack & Pinion	100x100x150 125x125x200 175x175x275 225x225x350 250x250x375	All 90 only
TORQUE HOSE ACTUATOR	1 2 3	20 each way 50 each way 200 each way	20 30 60	All Torque Hose	250x100x100 300x125x125 400x175x175	90 but greater possible with increase in 'h' dimension

distinct advantages. Both its size and price could be less than those of other actuators. The principle of operation of existing actuators was usually a piston/ cylinder arrangement with a linkage or rack and pinion to transmit the torque. Some actuators used a moving vane which sealed against the walls of a chamber. Each of these methods involved close-tolerance, high-cost engineering and, because of the inherent precision of the actuators, they were likely to be highly sensitive to dirt and the other contaminants commonly found in industrial air supplies. By comparison the T.H.A. did not require precision engineering and its main component, the hose, had the potential of being cheaply mass-produced. A further advantage of the T.H.A. was its much smaller number of components - perhaps 10 or 12 compared with more than 30 in some existing actuator designs.

In double-acting form (Fig. 5.2) the T.H.A. was less attractive. If 2 hoses were used to achieve the double-action, the size of the actuator became considerably greater than its competitors. If a linkage arrangement was used as in Fig. 3.3 the number of components and the costs would increase. However the advantages remained of simplicity of operation and resistance to contaminants - the latter admitted to be a serious problem in conventional actuators by representatives of pneumatics companies who were questioned by the writer.

The hypothesis on which the project was based (see Chapter 1.1) seemed to be supported by this work - although, clearly, the competitiveness of the T.H.A. would require further testing by more detailed market analysis and by the construction of prototypes. The one element which cast doubt on the eventual success of the project concerned the working life of the T.H.A. Several manufacturers quoted working lives of 'several million cycles' for their actuators. This indicated that the life of the Torque Hose had to be improved and stabilised, a point which received considerable attention before a satisfactory result was achieved.

2. Estimation of Value of Market

(i) Business Statistics

The main source of information available was the appropriate section of the Business Monitor Statistics (81) published by the Business Statistics Office. Pneumatic actuators were listed in Business Monitor PQ 333 as a separate category until 1974. After 1974 the classifications were revised and PQ 333.3 is one of several monitors replacing PQ 333. In this, actuators are not listed separately but as part of a group including positioners, intensifiers and allied equipment. Hence it has been necessary to make some assumptions to obtain a figure for actuators.

Total sales in 1975 of pneumatic control equipment in the U.K. by home producers was £44M. Import figures are not clear since figures for hydraulic, pneumatic power and pneumatic control equipment* are presented together.

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* The distinction between pneumatic power and pneumatic control equipment is not absolute. Power equipment is concerned with 'heavy' plant, i.e., compressors which produce compressed air and machines which use compressed air to carry out operations involving large forces. Control equipment consists of relatively small (sometimes miniature) components which use compressed air to perform low-force controlling functions, e.g., operating valves, moving flaps.

Similarly, export figures are also obscure, as reported in Government Trade Statistics, but more light is shed on this later by considering individual company performance. (Enquiries to the British Compressed Air Society and the Association of Hydraulic Equipment Manufacturers confirmed the unavailability of import and export statistics).

This work was originally circulated in Dunlop in August 1976. At that time, information was available to 1975. Further information for subsequent periods is now to hand, and is also included in this present account.

Sales figures for pneumatic actuators in the U.K. for the years 1972-1974 were :

Fig. 5.4 Value of Sales by Home Producers of Pneumatic Actuators in the U.K. for 1972-1974
(Source: Business Monitor PQ 333)

The large increase between 1973-1974 is impressive even when allowing for price inflation of 15.6%* and is outstanding compared with a decline in output in engineering and allied industries of 1.6%** in the same period.

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* Source : Retail Price Index

** Source : U.K. in Figures (1975 ed.)
Government Statistical Service, HMSO.

As already noted, sales figures for 1975 onwards were presented in a different form as shown in Fig. 5.5.

Fig. 5.5 Value of Sales by Home Producers of Pneumatic Products in the U.K. for 1975-1977 (Source: Business Monitor PQ 333.3)

Bearing in mind the trends in the years 1972-1974, the writer estimated that, out of Product Group 1, the sales of actuators for 1975-1977 were as shown in Fig. 5.6.

Fig. 5.6 Value of Sales by Home Producers of Pneumatic Actuators in the U.K. for 1975-1977

YEAR	SALES
1975	£4,000,000
1976	£4,200,000
1977	£6,800,000

The inclusion of cylinders as a separate category in Business Monitor PQ 333.3 is interesting. Many cylinders are eventually used in the same way as actuators. There was no way of measuring the true percentage of such cylinders but discussions with marketing experts in the pneumatics industry suggested that

50% would be a reasonable estimate. This meant that the revised figures for sales of pneumatic actuators became :

Fig. 5.7 Value of Sales by Home Producers of Pneumatic Actuators and Cylinders in the U.K. for 1975-1977

YEAR	SALES
1975	£7.500,000
1976	£8,500,000
1977	£12,900,000

On the basis of this information, it was stated in the report published in Engineering Group (82) that the actuator market was worth at least £4M in the U.K. from 1974 figures and perhaps £7.5M from 1975 figures.

(ii) Individual Company Performance

To confirm these trends, financial details were studied of a leading company in the field, 'Company A'. This company produces pneumatic control equipment including valves, cylinders and actuators. It was chosen because it was considered to be a typical company of its type and also because it had already been selected as a possible distributor for the T.H.A.* Company Reports and other information on file (83) gave the sales figures

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* See Section 3.10

presented in Fig. 5.8.

Fig. 5.8 'Company A' Sales Figures for 1972-1974
(Source: Company Report)

YEAR	U.K.	EUROPE	OTHER	TOTAL
1972	£2.5M	£6.7M	£0.6M	£9.8M
1973	£3.0M	£8.5M	£0.9M	£12.4M
1974	£3.7M	£11.6M	£1.3M	£16.6M

From U.K. figures in Fig. 5.8 it could be seen that 1973 showed a 20% increase on 1972. 1974 was 24% up on 1973 and 49% up on 1972. Comparing these figures with the Business Monitor figures already discussed, it was concluded that either Company A's performance was not as good as the rest of the industry or that the trends in actuator sales have been much better than for other pneumatic control items. Brief analysis of the results of other companies indicated that the latter explanation seemed most likely.

Company A's annual reports indicated that approximately 40% of its U.K. production was exported. Again consideration of other companies indicated similar export activities, although there was some variation. It was clear that while most companies were active outside the U.K., some apparently operated only in the home market.

Applying the information to the conclusion already reached that the value of the U.K. market was between

£4M and £7.5M, it was deduced that the total market home and abroad supplied by U.K. manufacturers could be in the region of £7M to £12.5M per year in 1976.

Two broad conclusions were drawn from this analysis of the value of the actuator market :

1. Although there was a wide spread between the upper and lower estimates of the value of the market, it was clear that even at its maximum, the market was very small in relation to Engineering Group's annual sales of about £70M. If a 10% share of total actuator sales could be taken by the T.H.A. this would probably represent a maximum potential of £1M turnover.* This meant that the project could never be regarded as a major new product for the Group.

2. Having accepted that the sales potential for the T.H.A. was small (relative to other Dunlop activities), it was nonetheless true that

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* Two assumptions are involved here. Firstly that most actuators are rotary in application rather than linear, so that the T.H.A. could be used in most cases instead of alternative equipment. Doubtless, applicability of the T.H.A. would be less than 100% in practice, reinforcing the need to regard the £1M as the maximum potential. The other assumption is that the T.H.A. would take 10% of the market. While carrying out the work reported in this Chapter, it was observed that 4 or 5 companies were predominant in the market. If these leaders had something like the 70%-80% share often attirbuted to market leaders, then if Dunlop became one of them, it could reasonably expect to capture around 10% of the total business.

pneumatic equipment, particularly actuators, did constitute a healthy market compared with other branches of engineering production.

The overall conclusion from this analysis was that the T.H.A. was a suitable new product to be included in a selection of minor new products which together would have turnover high enough to justify creating a new section of business within the Group.

5.5 Data from Primary Sources - Practical Market Research

The information obtained from secondary sources gave a reasonable 'feel' for the pneumatic actuator market. However, it was clear that more specific information was needed before design and development of a pre-production prototype could start. The answers to a number of questions had to be obtained, such as :

- Who are the main purchasers of pneumatic actuators ?
- From whom do they purchase, manufacturers or stockists ?
- What features are sought in actuators - small size, single or double acting, low air consumption, etc. ?
- Which actuators are most widely purchased ?

Discussion with supervisors and colleagues confirmed that this information should be obtained so that the engineering development work could be organized for greatest effectiveness. It was agreed that practical market research would be required to answer the questions listed above.

No facilities to undertake this work were available in Engineering Group at the time, although the Corporate Planning Department were able to advise about different approaches to the field work. Hence, the writer decided to investigate market research methods for himself and to devise a programme of practical work which he could carry out.

Study of market research literature indicated that two key decisions had to be taken :

1. What sample of the total population of actuator purchasers should be chosen ?
2. What method of research should be used out of those available ?

As far as deciding on the sample to be used, the advice of Williams (84) was followed. He points out that in industrial marketing research it is always difficult to define the 'population' in such a way that an obvious,short list of firms can be selected to form the sampling frame. He suggests that the best approach is to list the applications of the product, to indicate broadly the section of the industrial population from which information will have to be obtained. However, he warns that deciding which firms to include in the sample is difficult without experience of the field and several pilot runs might be necessary before a sample can be used with confidence.

Wilson (85) also refers to the difficulties of defining samples in industrial market research and argues that the only practical approach is what he calls 'sequential' sampling, i.e., selecting a sample by informed guess-work and modifying it in the light of the information revealed during the early runs of the survey.

Consequently a list of applications of pneumatic actuators was drawn up and this is shown in Fig. 5.9.

Fig. 5.9 List of Potential Applications for Pneumatic Actuators

Flap operation - in heating and ventilating
Lifting operations - materials handling
Clamping operations
Vehicle applications
Marine applications
Valve operation
Stirring operations - of paint, chemicals, etc.
Military applications
Architectural use - e.g. for opening doors, partitions etc.
Agricultural use
Sorting operations - e.g. by the Post Office
Barrier control - in car parks, airports, etc.
Machine tool applications
Mining operations

Fig. 5.10 Firms Likely to be Using or Specifying Pneumatic Actuators

Application : Lifting operations - materials handling

Probable users : General Industrial

Manufacturers : Coles Cranes Ltd.
Hyster Ltd.
Herbert Morris Ltd.
Martonair Ltd.
Multi-Pneumatics Ltd.
Stewart-Warner Ltd.
Thor Tools Ltd.
Underground Mining Ltd.
Globe Pneumatic Engineering Ltd.
Aabacus Engineering Ltd.
Air Automation Ltd.
Marine Engineering Ltd.

The list was compiled from information gathered during the research into secondary sources (e.g., trade directories, product brochures) and also from less formal activities such as visits to exhibitions, meetings, other companies, etc. From the applications list, other lists were built up, of firms considered likely to be purchasing or specifying actuators in reasonable quantities. An example is shown in Fig. 5.10. This was the 'first stab' at selecting a sample which it was intended should consist of about 500 firms in total.

The second problem was to decide which method of research was most appropriate. Again, study of various writers was undertaken and a number of suitable methods were identified :

Postal questionnaires

Telephone interviews

Personal interviews

Since the researcher was working alone and his time had to be allocated between the engineering and marketing aspects of the project, it was decided that the postal questionnaire method would be best.

The questionnaire was designed with a number of points in mind :

1. The objectives of the research as stated earlier in this section.
2. The need to be economical in the design of the questionnaire since response falls off the greater the number of questions asked.
3. The need to avoid ambiguity in the questions.

The resulting questionnaire is shown in Fig. 5.11. Before embarking on the first run of the survey, it was decided to test the questionnaire by sending it to a number of divisions within Dunlop. Six forms were sent, each with the covering letter (shown in Fig. 5.12) and a drawing of a typical pneumatic actuator to eliminate any doubt about the type of product being investigated. Three replies were obtained and it was found that useful answers had been given. Follow up of the three forms not returned, indicated that antipathy to surveys, rather than problems with the questionnaire, was the reason for non-cooperation.

It was late in October 1976 when this point of preparation to explore the market had been reached. The full survey was never undertaken because of the events described in Chapter 3. Amongst the changes which occurred, two, in particular, were responsible for the practical market research exercise being shelved :

1. Engineering Group Management decided to use other companies as distributors of the product and to use them as the source of market information.
2. The writer's attention was directed to urgent engineering problems and his responsibility for marketing work was transferred to another member of the newly appointed project team.

PNEUMATIC ACTUATOR INFORMATION SURVEY

Date of recent purchase(s) of actuators ? ....

....

How many did you purchase ? ....

If you purchase regularly, can you give an approximate annual figure ? ....

Were these actuators in your recent purchase double acting type or spring return ? ....

What size were the actuators ? ....

....

What make were the actuators ? ....

Any particular reason for choosing this make ? ....

....

Who did you buy them from ? e.g. stockist, manufacturer, etc.

....

What is your application for these actuators ? e.g. valve operation, flap operation, etc. ....

....

Have you any comments about these actuators or others that you are familiar with ? e.g. design points, reliability, etc.

....

....

....

....

THANK YOU FOR SPARING THE TIME TO PROVIDE THIS INFORMATION.
PLEASE RETURN THE FORM IN THE ENVELOPE PROVIDED.

In the case of any query please ask for Mrs. C. McDonald on Coventry (0203) 88733 - extn. 223.

MHO/clm
28.9.76.

FIG. 5·11: TEST QUESTIONAIRE SENT TO DUNLOP DIVISIONS (ORIGINALLY A4 SIZE).

5.6 Market Information from Potential Distributors

Shortly after the project team was set up, in November 1976, it was decided by Engineering Group Management that the T.H.A. could not be distributed through any existing Dunlop channels. It was reasoned that the Group had no similar products with which to make up a product range and had no experience of selling pneumatic control equipment. Consequently, it was decided that suitable companies should be approached to learn if they were interested in selling the T.H.A. Furthermore, it was expected that potential distributors, offered the opportunity to stock an interesting new item, would provide Engineering Group with accurate (since they knew their business) market information on which a business plan could be based.

The writer had some doubts about these decisions, but had no influence over these aspects of the project. He stated his opinions and noted the events which followed.

In the first place, there was an inconsistency in the argument about distribution channels. Engineering Group had recently launched another new product about which it had no previous market experience. However, as a rule, Engineering Group only introduced products in familiar markets, i.e., vehicle, tyre equipment and aviation industries. A second point was that it was the stated policy of the Engineering Group to diversify into new business areas. It seemed a contradiction to expect to do this whilst remaining in familiar territory.

Practical reasons for criticising the use of distributors were (1) the reduction it would cause to gross profits because of the distributor's expenses and (2) the loss of control over selling prices. On the other hand, it had to be conceded that existing operators ought to know their markets and would provide quick and accurate penetration when the actuator was eventually launched.

The attitude of Engineering Group management over the distribution of the T.H.A. calls into question the effectiveness of the new product screening process. This was carried out by a team of senior managers. Whatever criteria were used for screening, method of distribution and relevance to company policy would usually be primary considerations. In this case, these points seem to have been unsatisfactorily analysed with the result that the concept of the project was changed abruptly.

The most interesting outcome of the distribution decision was the information obtained about potential demand for the product. Confidential disclosures about the T.H.A. were made to two companies who seemed suitable to become distributors. They were selected from amongst the contacts of the Product Development Director. Company A sold general pneumatics products while Company B did not yet sell pneumatic actuators (but wanted to) although it did sell electrical actuators and concentrated on a specific segment of the market (valve actuation).

Both companies reacted with enthusiasm when introduced to the T.H.A. Company A agreed to give estimates of the turnover that the actuator could be expected to achieve, if it could be provided with a technical specification. In fact, the information from Company A was of doubtful usefulness. Estimates were given with very wide margins of error and when alternative technical specifications were offered, it was clear that the Company had no idea (or was unwilling to disclose) what sort of market existed. When presented with the information discussed in Section 5.4 of this chapter, the reaction was that it 'seemed about right'. It was surprising that no qualifications of any kind were suggested.

When it was suggested that Engineering Group might reconsider and distribute the product itself, Company A reacted by saying that if excluded, it would seek loopholes in the T.H.A. patent and attempt to produce its own version of the actuator.

In contrast, Company B never claimed to be able to quantify the market since it was not yet operating in it. It simply reported that it considered there to be a profitable market which it was keen to enter as soon as possible. Several months after the first discussion took place, the Chairman of Company B - a gifted entrepreneur - remarked that the concept of the Torque Hose had set off a train of thought for him. The result was that he was now working on the development of an actuator which had some resemblance to the T.H.A. but worked on a different principle.

These observations give rise to a number of conclusions about the seeking of market information and the disclosing of product information in order to get it.

1. It is likely that a company operating in a market will have better information than a company which is outside the market (like Dunlop in this case) but wishes to enter it. However, even with the prospect of an interest in a new product,it is unlikely that the knowledgeable company will disclose any more information than would be found from a competent market analysis by the outside company.

2. The timing of any disclosure to a potential distributor is important. If it is done too early in the development stage, in the hope of securing useful information, there is the risk that the technical data might be exploited. If it is done too late, much development time may have been wasted in perfecting irrelevant technology. On balance, it seems better to take the latter risk - which can be minimised by good marketing work.

3. There is a need within Engineering Group for a reassurance that marketing work carried out by its own

personnel can be of high quality. Perhaps there is a misunderstanding of the process of marketing work and the need is for a greater awareness of marketing techniques within the Group. Burns and Stalker (86) found that the most successful innovative companies were those where the engineers on each project carried out their own market research work.

It is not true that the only accurate information comes from the 'horse's mouth'. A particularly apt illustration of this is provided by Wilson (87). He comments that some information which the British Compressed Air Society refuses to release to non-members is freely available from another source, and would be discovered by any reasonably competent researcher.

4. Once disclosure is made to another company, there is considerable pressure to continue with the technical development. In this case, an unnaturally high level of optimism and encouragement was maintained by Company A without any definitive marketing information to support the attitude. Naturally, it was in the interest of Company A to encourage Dunlop to carry out as much development work as possible to provide new products. Since it was not sharing the development costs, Company A had nothing to lose and possibly much to gain.

CHAPTER 6

ORGANIZATIONAL ASPECTS OF THE STUDY

6.1 Introduction

Work on the Torque Hose project reported in the previous chapters, was carried out during a period of considerable organizational change in Engineering Group. For a number of years, the Group had suffered a decline in its activities because the main industries which it supplied had also declined. During 1976 and 1977, steps were taken in the Group to introduce new business activities to reverse the trend. The Torque Hose project featured in these actions and the writer was able to examine several forms of innovative organization as they were applied to the project and to other product development exercises.

The project was a part of three distinct organizational systems during the period of 30 months or so that the writer was involved with the work:

- The Product Development Unit
- The Special Project Organization
- The Venture Operation.

6.2 The Product Development Unit

Until it closed in July 1976, the Product Development Unit (P.D.U.) was concerned with the development of new products which could be put into production by the Divisions of Engineering Group, to expand the range of their business actities. Before describing the organization and operation of P.D.U., its place in relation to the rest of Engineering Group and Dunlop must be shown.

Engineering Group's position in the structure of Dunlop Limited is shown diagrammatically in Fig. 6.1. In 1976, Engineering Group employed 4,711 people out of the Dunlop U.K.total of 43,309 (10.9%) and accounted for £58M of the total U.K. turnover of £463M. (88).

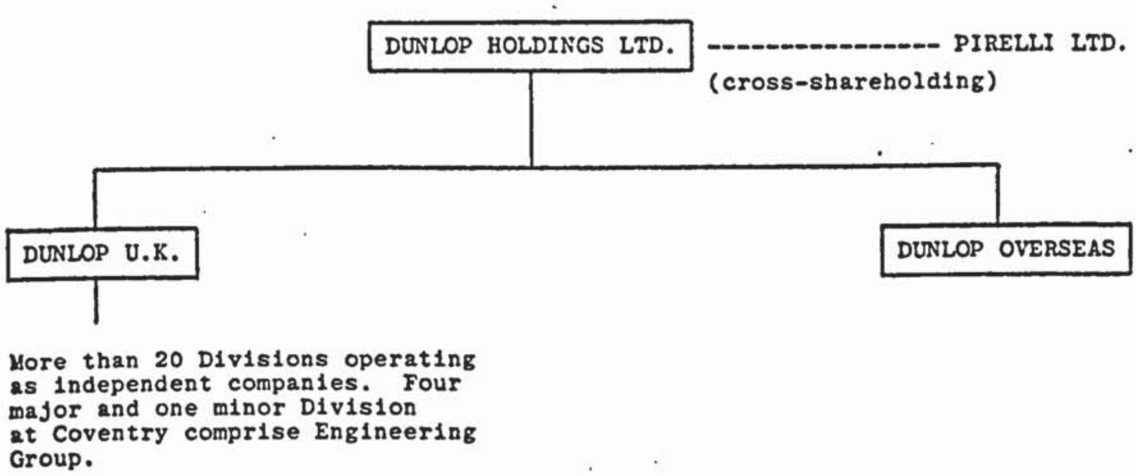


Fig. 6.1 Simplified Structure of Dunlop Limited in 1976

Despite these impressive figures, Engineering Group had suffered a decline in business as its main customers, the vehicle and aviation industries, had also declined or changed their purchasing requirements. During the 10 years up to 1976, the Group's turnover had fallen in real terms by some 25% and more than 2,000 jobs had been lost (89).

P.D.U. was set up to help reverse these trends by developing and introducing new products into the Group. It was headed by a Director who reported to the Group Director as shown in Fig. 6.2. Hence P.D.U. was functionally independent of any of the operating divisions and was represented by its Director at the most senior management level.

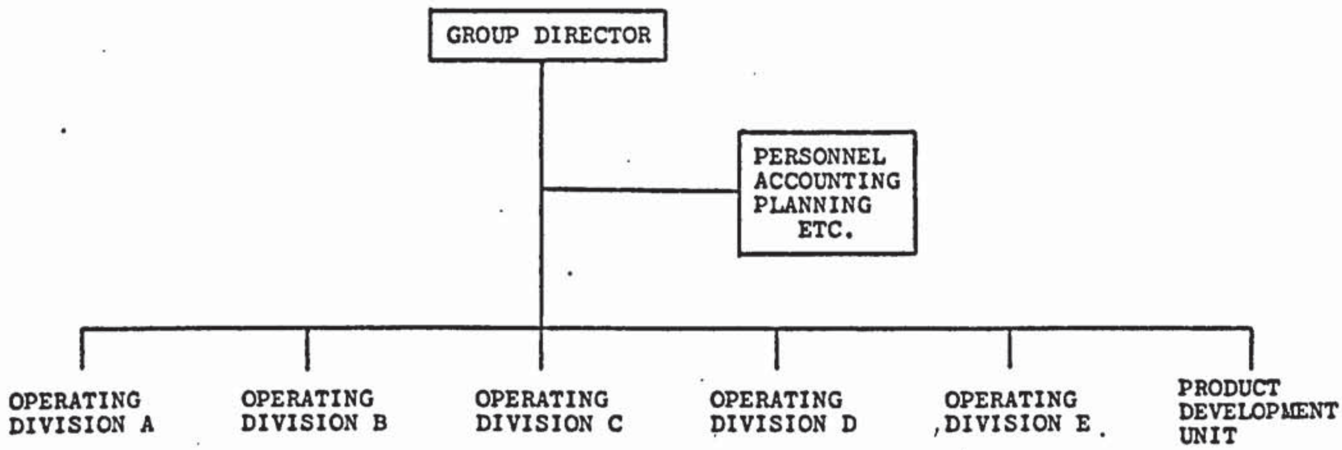


Fig. 6.2 Simplified Structure of Engineering Group Before July 1976

The organization in Fig. 6.2 corresponds to pattern 3 in Fig. 2.8, one of the several organizational forms for innovation described by Mueller. It is most interesting that Mueller's chief criticism of this model is that 'I' is dependent on 'D' for resources. From discussions with the Director of P.D.U., the writer found that the Group Director, 'D', (there were several during the life of P.D.U.) was not always sympathetic to the objectives of the Unit and funds were not always freely available. Undoubtedly the Group Director was under strong pressures from the heads of other divisions - all of whom were strongly committed to production activities. The weakness of the position of the P.D.U. Director is clear if one considers the size of the turnovers of the Divisions relative to the P.D.U. annual budget :

Division	Relative Size of Budget/Turnover
P.D.U.	1
Division A	150
Division B	115
Division C	45
Division D	5
Division E	20

Another problem was that each of the divisions had its own development departments. These were chiefly concerned with improvements to existing products and processes but their existence had two disadvantages as far as P.D.U. was concerned.

1. Senior managers were able to claim that product development was already catered for in their production divisions (although declining turnover trends did not bear this out).

2. The transfer of new products from P.D.U. to the divisions was blocked because the 'not-invented-here' factor was encountered. The writer observed at first hand the reactions of divisional development managers to some P.D.U. products. Even with top level support (i.e., Group Director) resistance to, and denigration of, the products was sometimes protracted and intense. Most of the reasons which Bright has listed (Fig. 2.1) for resisting innovations were seen to be present in Engineering Group.

Adopting Mueller's notation, as used in Fig. 2.8 the innovative aspects of the organization can be described as in Fig. 6.3.

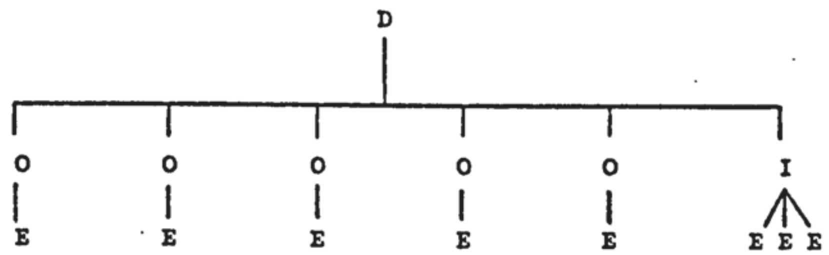


Fig. 6.3 Innovative Organization of Engineering Group

In addition to the disadvantages already noted, it can be seen that at all points, the creative activity represented by 'E' was effectively shielded from'D', the chief decision and policy maker. The senior managers represented by 'O' considered the mainenance of the production activities to be their main preoccupation and resisted any hinderance or threat to their established methods. The P.D.U. Director represented by 'I' experienced resistance not only from 'O' but also from 'E' reporting to 'O' and, in many instances, from 'D' under the influence of 'O'. The result was an innovative stalemate. In the case of one new product, the P.D.U. Director had to turn his Unit into a production centre in order to launch the product after it had been blocked by the rest of the Group. This meant that other development work had to be sacrificed to provide the production facilities. Even so, it was not until much later, after substantial reorganizations (including the closure of P.D.U.) that the product was finally adopted by the Group.

6.3 Organization within P.D.U.

In essence P.D.U. consisted of a number of project teams and a comprehensive workshop. Each of the teams was headed by a project engineer who had development engineers and design draughtsmen under his control. The workshop, which was managed by a superintendent, provided the rigs and prototypes required by the project teams. Together with a number of other members of staff, the project engineers and the workshop superintendent reported to the Director as Fig. 6.4 shows. In fact, the organization was more informal than the diagram suggests. The Director took a close personal interest in each project at all levels and was a source of many inspirations. A very effective service was provided by the workshop, its members freely co-operating with the project team members. In this way, components were built very quickly and modifications were usually dealt with immediately.

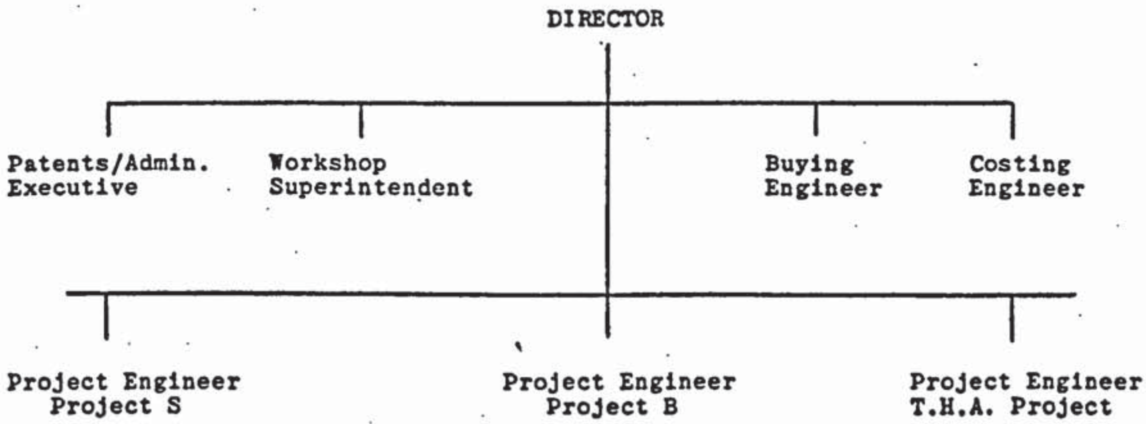


Fig. 6.4 Simplified Structure of Product Development Unit

If the Director is seen as the 'mission' controller the organization of P.D.U. was very similar to the Modular Concept (Fig. 2.6) described by Basil and Cook. Each of the project teams certainly had a 'mission', namely the development of a product from conception to completion. A weakness of this concept, especially where one man is the controller, lies in the difficulty of maintaining a balanced interaction between the project teams and the various functional specialisms. For example, the P.D.U. Director was a practical engineer and was very effective as a technical adviser and co-ordinator. As a result, the technical development of the projects tended to get out of tune with their marketing development.

The problem was partly caused by lack of liaison with marketing experts and partly by attitudes within Engineering Group (and much of the rest of Dunlop) which meant that marketing specialists were excluded in the first place. Despite falling turnover, the need was not seen in Engineering Group for effective marketing, to discover what products and prices customers required. A corporate planning department was concered with long range planning and various marketing departments on the site were concerned with advertising and sales administration. No senior staff were employed to carry out market research or product evaluation.

In P.D.U., the Director certainly made attempts to investigate markets and product potentials, but of necessity this was limited in scope and was generally conducted via his industrial contacts. Despite this, compared with the models proposed by Twiss of the product development process (Figs. 2.2 and 2.3), the activities in P.D.U. were strongly product oriented rather than market oriented. The consequence of this was that products were sometimes extensively developed, perhaps over several years, only to be rejected by the markets they were intended to exploit.

Because of the product oriented development process, ingenious and complicated designs were sometimes encouraged while competitors, with better awareness of their markets, favoured orthodoxy and simplicity. However, the problem was not entirely to do with the way the Unit organized its development. In setting up P.D.U., Engineering Group had decided that the strategy should be to develop new products outside its normal activities so that its base might be broadened. When the Unit produced novel products, the Group tended to reject them on the grounds that it did not have experience in the new markets. This paradox persists in Engineering Group, even though P.D.U. has been superceded by other product development operations. The writer is convinced that the remedy lies in increased use of marketing techniques. As long as customer needs are assumed rather than investigated, new product operations will have high failure rates and confidence will remain low, a view endorsed by many of the writers discussed in Chapter 2.6. The manifestations of this low confidence were clearly seen when they affected the T.H.A. project - inconsistent management support for the project coupled with distrust of the new market involved.

6.4 The Special Project Organization

As part of a series of reorganizations initiated by a new Group Director, P.D.U. closed in July 1976. The major development projects were transferred to Divisions within the Group to be put into production, but the T.H.A. project and "Project W" were not ready for production. No alternative development operation had been set up to replace P.D.U. but it was agreed that work should continue on the two projects.

The Director of P.D.U. became the Board member responsible for advising on technical development within the Group. In this position of Product Development Director, he was working in a staff function and no longer had operational responsibilities. However, it was decided that the T.H.A. project and Project W would be placed under his control. At this stage the structure of Engineering Group was as shown in Fig. 6.5.

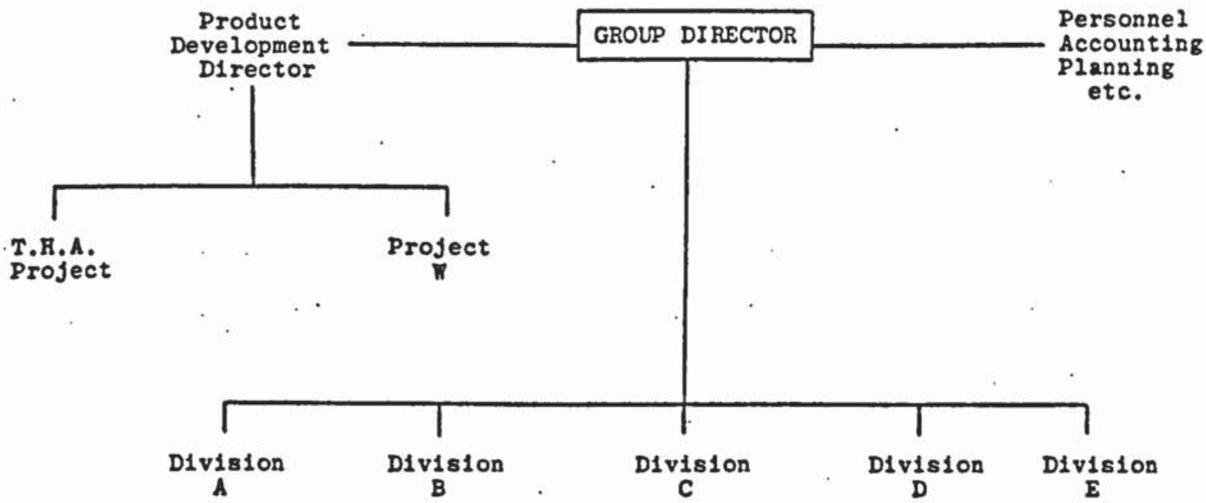


Fig. 6.5 Simplified Structure of Engineering Group After July 1976

In some respects the two projects were being organized as previously in P.D.U. The same Director was involved and the objectives remained the same. However, the day to day running of the projects was different. Facilities and expertise enjoyed within P.D.U. were no longer available. For example, the P.D.U. workshop had been disbanded and now the Project Engineers had to negotiate for components to be made in various workshops on the Coventry site. It has been noted already that attitudes in the Divisions were not sympathetic to development work. Securing co-operation in the maufacture of components was not easy ; priority was always given to production work so that the development projects were often frustrated. As the Product Development Director's function was now an advisory one, his influence with divisional managers over the use of production facilities was not great.

Similarly, with the P.D.U. buying operation no longer available, divisional buying departments had to be used. These departments did not give a high priority to work which originated outside their divisions.

This structure was a temporary arrangement for the T.H.A. project - although Project W has remained in this form - and so its problems will not be over-emphasised. There is a useful lesson to be learned though, since this is a structure for innovation which might seem attractive at first sight. It offers the advantage of economy since special facilities such as buying, workshop, patents, etc. are not required but can be 'borrowed' from existing departments - especially attractive if there is some 'slack' in the normal operations. But the overwhelming disadvantage is that the innovative projects are seen as foreign activities.

Using the same notation as before, a schematic diagram of this structure is shown in Fig. 6.6.

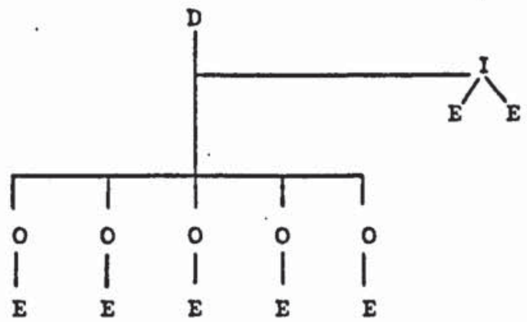


Fig. 6.6 Innovative Organization of Engineering Group After July 1976

Comparison with Fig. 2.8 shows that this is similar to Mueller's 'Pattern 4'. He suggests using a task force which also includes 'O', instead of using 'I' alone as the linkage between the development and production. This should work well where the product being developed is one which 'O' supports, In the case where the new product is resisted, the participation of 'O' in its management is likely to be detrimental since 'O' can fight from within to influence the development at first hand. The writer observed this to be the case with Project W where this form of organization evolved.

The project engineer reported jointly to the Product Development Director, 'I' and Divisional Managers, 'O'. The latter took every opportunity which their involvement offered, to place obstacles in the path of the new product.

Whatever the reasons for this resistance to innovation (some are suggested in Chapter 2.3) there comes a point where the value of perseverance has to be questioned. It is one thing for a Chief Executive to insist that new products to be introduced - but another for such instructions to be given anything other than lip service by managers who do not want changes to take place. It has been noted in Chapter 2 that resistance to change is a feature of older companies rather than younger ones. The Divisions in Engineering Group and their products had evolved over many decades.

The alternative to the expansion of an existing business activity is the creation of a new one. This was the philosophy behind the next innovative structure which was applied to the T.H.A. project. It had been decided that the existing Divisions might have to be allowed to decline while new divisions would be developed which would grow, in due course, so that a growth in profitability of the Group as a whole would be maintained - the ecosystem principle, discussed in Chapter 2.

6.5 The Venture Operation

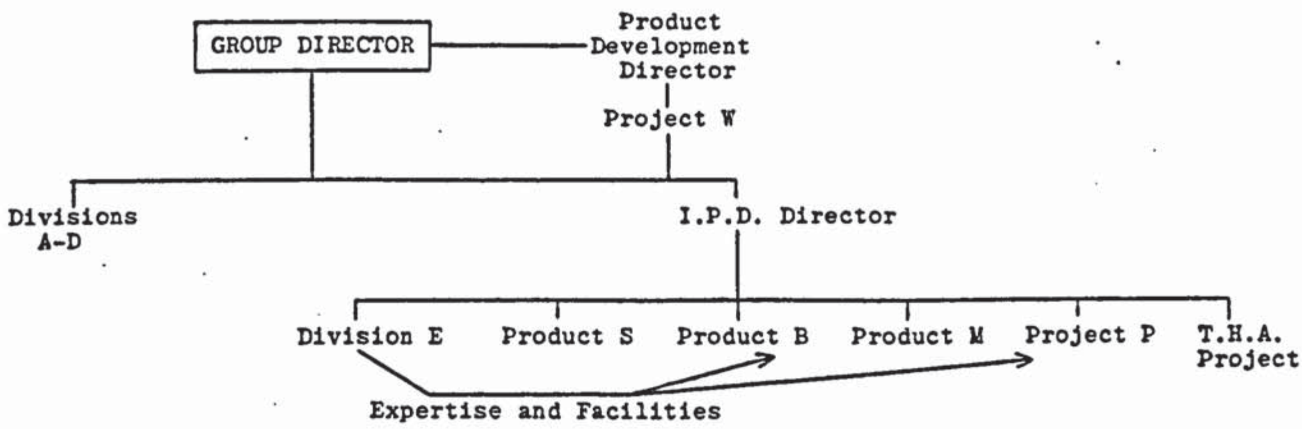
Towards the end of 1976, a new division was formed in Engineering Group, called the Industrial Products Division (I.P.D.). The new division was to be a nursery for new businesses - it was planned that innovative projects would grow quickly so that I.P.D. would become a major division in the Group.

The new division incorporated the existing 'Division E' which had been extensively rationalized. Its chief became the Director in charge of I.P.D., a new manager was appointed to Division E. In addition to Division E the following were incorporated in I.P.D. during the first year of operation.

1. Product S)
2. Product B) These were the two major products which came from P.D.U. on its closure. Neither had yet begun to prosper commercially.
3. Product M - A new product developed at Coventry some years earlier. It had enjoyed only moderate success but was considered to have good potential.
4. Project P - A major development project brought into the Company from an international research institute.
5. T.H.A. Project

The new division was intended to be organized on 'Venture' lines, the intention being that each product or project would develop as an independent operating unit. In each case, a Product Leader was appointed who was given responsibility for all aspects of the operation - development, production, buying, finance, personnel, etc.

An outline of the new organization is given in Fig. 6.7. Although Division E had been established for many years, its inclusion in the new innovative division could be justified on two grounds :



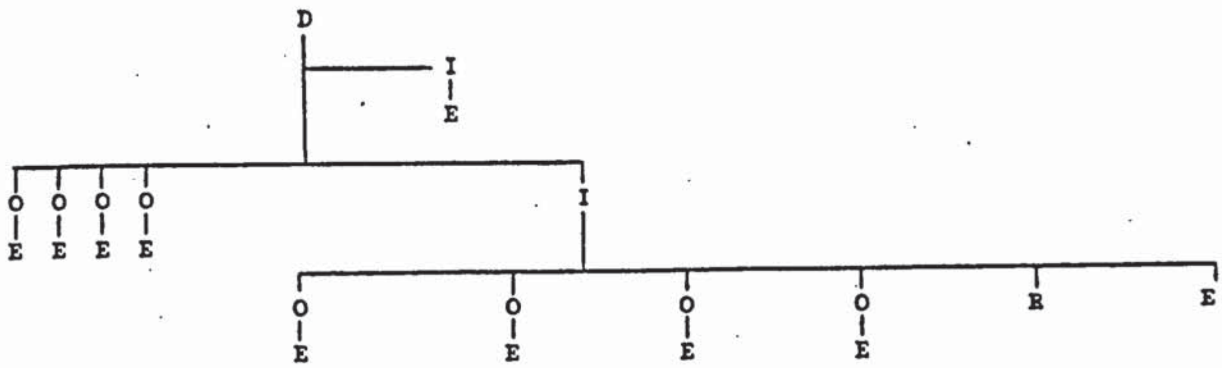


Fig. 6.7 Organization of Engineering Group with Industrial Products Division after January 1977 (upper) Diagram Showing Innovative Organization (lower)

1. Recently, it had been rationalized and reorganized and was now set for a period of profitable expansion, similar to the other parts of I.P.D.

2. It contained facilities, such as a workshop, and expertise in areas like engineering design and accountancy. These were needed by the other projects in I.P.D. and it seemed sensible to use Division E rather than set up new departments.

6.6 Effect of Bureaucracy and Inconsistent Management Support on the Venture Operation

As far as the T.H.A. project was concerned, problems soon arose with Division E. Orders placed with the Division's workshop for components and rigs were subject to delay when the Division's own requirements took precedence. Very soon, it was clear that quicker (and often cheaper) service could be obtained by using external engineering companies. This also applied to other services which could have been supplied by Division E.

The most fundamental drawback to the association of Division E with the T.H.A. project arose over points of administration. In setting up the T.H.A. project as a venture group, the intention had been to give team members freedom of action. A budget of £40,000 for the first year's operation had been set. It had been resolved that the project should move as quickly as possible and not be restricted by 'the system'.

In practice, it was difficult to avoid 'the system'. Initially, all purchases were made by team members using order forms provided by the buying department of Division E. It was not long before the buying department began to question some of the purchases, particularly on points of price, delivery, specification and suppliers used. T.H.A. project team members were soon required to hand over all purchasing to the buying department and no longer had direct access to suppliers.

This and other intrusions of bureaucracy seriously undermined the venture concept. It cannot be denied that the team members were relatively inexpert as purchasing officers but the sums of money involved were not large. Being compelled to use the system reduced the enthusiasm of the team members and also meant that much longer delays were experienced whilst paperwork and procedures were carried out.

The venture concept of the T.H.A. project was also undermined by actions at the most senior level in Engineering Group. The project had been selected for I.P.D. by a committee of board members which had made its decision on the basis of technical and marketing information provided by the writer and by the Product Development Director. For several months after the project moved to I.P.D., the Corporate Planning Department issued a succession of appraisal documents to the Project Leader. Although the project had already been established in I.P.D., this department felt the need to apply its own selection procedure. Once again the bureaucracy of the system was adversely influencing the progress of the project, particularly the speed of the development work.

This lack of progress drew criticism from the management of Engineering Group. When a major technical problem arose soon after, the management lost faith in the project and virtually closed it down by posting elsewhere all team members except the writer and by withdrawing its budget.

In the opinion of the writer, the reason for this lack of consistent top management support was not because the T.H.A. product concept was weak. The problem was that Engineering Group required new business to be opened up quickly but it did not really appreciate the unpredictability of the product development process. Thus when the T.H.A. project was set up in I.P.D., it was rated very highly until development sangs occurred. Similarly Project P, a major project much larger in scope than the T.H.A. project, was viewed with concern when development target dates slipped or unanticipated problems were encountered. As the study of a major British innovation shows - the Float Glass process for plate glass - solid management support is essential for success. Pilkington, the inventor of the process tells how after fourteen months of heavy expenditure with only completely unsaleable glass produced, his board of directors remained firmly behind the project. The process eventually took seven years to perfect (90).

6.7 Organization Within the Venture Groups

It has been observed (Chapter 2.3) that a feature of venture groups is that they are usually informally structured and have a 'free wheeling' atmosphere. Authority is diffused in the group and the function of the team leader is not so much to direct operations but to co-ordinate through involvement. Division E and the three product groups - i.e., product B, product M and product S - were strongly hierarchical in structure before they tranferred to I.P.D. Once in I.P.D. there was little practical incentive for change. The product groups remained in the same locations and, by and large, were composed of the same managers and staff. Many of the staff were senior both in terms of years and experience, and had no desire to move away from the security of a system they understood. The main incentive in a venture organization - the prospect of advancing rapidly with a successful product - was of little appeal to most of them. Dunlop was considered to be a benevolent employer, tolerant of both mediocrity and excellence, and unlikely to penalize the members of unsuccessful product groups.

At the time of writing, some 18 months after the creation of I.P.D., the groups remain rigidly structured and the products are still failing to make a real impact on their markets. The writer believes these facts are a consequence of each other - a market success would bring down the hierarchical defences ; on the other hand an organization which was goal-centred rather than role-centred might well be the key to achieving market impact.

A most recent development has been to relocate the Product B group to a small factory some 15 miles from the Coventry site. It has been noted elsewhere in this thesis that successful innovative groups tend to be those which are organizationally and geographically spearate from the main parent activity. Therefore, this seems a wise step and it is to be hoped that a more effective organization will result. An infusion of new personnel is encouraging but a report of controversy about a £400 desk strikes an ominous hierarchical note.

Unlike the other groups in I.P.D., Project P and the T.H.A. project did not yet have a product to sell - they were both development projects. In 18 months Project P (which was based at Coventry) had grown into a group of about 20 people headed by a project leader. Once again, the organization was observed to be strongly hierarchical. Within this small group, several layers of command had been created. A strong division appeared between the 'workers' who were physically involved in the development work and the 'administrators' who were planning and directing the project. The polarisation had a physical aspect - the administrators secured comfortable, carpeted offices on the 1st floor ; the workers were allocated inferior accommodation on the ground floor.

Insufficient practical involvement by the administrators certainly reduced efficiency in the development work as resentment and frustration became topics of concern. Communications between the parties deteriorated to the extent that, for example, requests by the workers for protective clothing were made to the Engineering Group Safety Officer rather than to the Project Leader or his assistant.

An organic type of structure might have been much better for this project, encouraging all participants to work together towards a common goal, and hence to share the rewards of success. Instead, the mechanistic form which developed, held the promise of achievment and reward only for the senior members of the group. In fairness, it must be said that an informal organization would be very difficult to construct within the confines of Engineering Group which is strongly hierarchical. This indicates that geographical separation from the established organization is essential if development work is to be effective, supporting the view of Burns and Stalker (91) and other management writers.

A final criticism of this project concerns the ways in which the skills of team members were used. In an organic structure all members would have the opportunity to contribute in their most effective way. In the rigid structure which developed in the project, individuals were directed to tasks which did not always make best use of their skills. Hence, young graduate engineers and material scientists were allocated labouring duties when they might have been tackling some of the technical problems. Thus, the formal structure could not enable benefit to be derived from the multi-disciplinary composition of the group, a feature which Hill & Hlavacek (92) stress as important in successful venture organizations.

The Torque Hose Project was rather more informal - not surprising with only 3 members in the group. Nevertheless, the project leader was encouraged to establish a hierarchy and some of the signs appeared - the better office with a carpet, the use of a girl to answer the telephone. In Engineering Group it seems that manifestations of success are sought far more eagerly than success itself, and it is impossible for an individual to be immune from the pressures.

6.8 Matrix System Applied to the T.H.A. Venture Group

The most interesting feature of the organization of the T.H.A. project at this stage, was the effect of a form of matrix management which was applied to it.

The group responded through the Project Leader to the Director of I.P.D. on matters of day to day administration and on the aspects of the project concerned with the development of a business. The I.P.D. Director authorised expenditure, agreed the scheduling of the project and set the policy for the business. On technical matters, the group reported to the Product Development Director. The advantage of this dual reporting was that each Director was able to advise in the areas of activity in which he was an expert. A diagram of this organization is shown in Fig. 6.8.

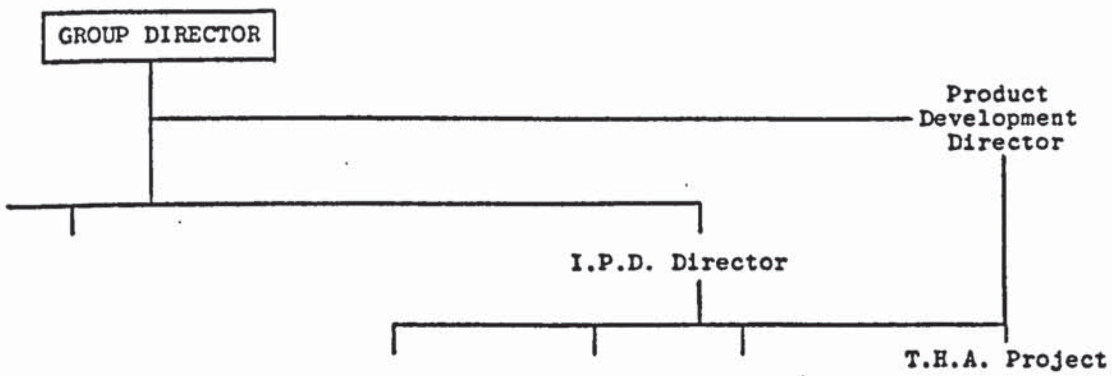


Fig. 6.8 Matrix Structure in Torque Hose Project Venture Group

This hybrid system did not work satisfactorily. On the one hand, the team was attempting to operate as a true venture group, i.e., working as an independent business, by-passing the normal system where possible and generally 'learning by doing'. On the other hand, the group was being directed by two senior managers of the parent company, each with strong views on certain aspects of the work. Had the involvement of these managers been limited to the giving of general advice, the hybrid system might have worked. As it was, the project leader found the venture system impossible to co-ordinate satisfactorily - instead of decision making 'on the job' by team members, formal progress meetings had to be held with the two Directors.

Once again it was clear to the writer that the venture concept was being undermined by the existing organization of Engineering Group. Ideally, the Project Leader would have had sufficient authority to use the project budget to finance a move off the site. In fact, authorisation was required for quite modest expenditures, so this could not be done.

It can be argued that the T.H.A. venture group was a venture group in name only. In the light of operational experience it must be conceded that this is largely the case but the fact remains that it was the initial intention of Engineering Group management to adopt this system in the I.P.D. projects. In some important aspects, the organization of the projects has differed from earlier innovative activities in the Group. The project members have had the freedom to sub-contract design and engineering work outside the Group, if necessary. The influence and restraints of 'the system' have been reduced, for example, by creating each project as a cost centre for accounting purposes, instead of attaching it to an operating division.

What the writer has concluded from this examination of the use of the venture concept for product innovation, is that partial commitment is not enough for success. A whole-hearted adoption of the concept is necessary for the benfits to manifest themselves in terms of new products. In more detail, the following specific conclusions arise out of the Engineering Group venture experiment.

1. Inadequate initial screening of projects and lack of marketing awareness. High initial enthusiasm by Engineering Group management for the venture idea probably resulted in some of the projects being selected without proper consideration of their potential. For the T.H.A. project this resulted in a retrospective appraisal by the Corporate Planning Department after the project had been already selected which caused uncertainty and frustration for the team members.

The marketing information obtained before the project was selected was not sufficiently investigated by the selectors. More disturbing, the information was freely embroidered and distorted in planning the progress of the project but no real demands were made for verification or deeper analysis. Stevens (93) claims that most venture failures arise because neither the product nor the manager is sufficiently outstanding. In too many cases, he says, the product does not have either a sufficiently large sales potential or a big enough profit margin to provide the foundation for an independent business. On the basis of the information available, Engineering Group could not have forecast sales or profit with sufficient certainty to justify the expectations which the T.H.A. project generated.

More fundamental was the failure to be truly market-oriented in the selection of projects. Engineering Group was historically weak in terms of marketing and much previous innovation had failed because technical ingenuity had taken precedence over gaining an understanding of the user's needs. Several excellent products had been devised for which it was eventually found that only insignificant sales could be obtained. This does not mean that speculative development work should not be undertaken, but that it should not be the basis for a venture exercise. Vernon (94) indicates that the success of a venture operation in I.C.I. stemmed from a chance technical discovery ; but the discovery was not exploited until a marketing analysis indicated a user need which it happened to satisfy.

2. <u>Lack of commitment by top management</u>

Faced with the news of technical problems with the T.H.A. project, the reaction of the management was to take resources away from it. Conversely, when progress and prospects looked good, ever more optimistic targets were set. The point here is that once a potential project has been thoroughly analysed and then selected, the venture team should be insulated from inconsistency. Whilst the company was naturally anxious to see projects succeed, it should have been ready to accept that some - even a majority - might fail, and the best chance of success would be assured by steady support.

3. Lack of protection from the organization. This has been discussed at length in this chapter and the point will not be laboured here. However, it will be repeated that the effect of organizational interference was to divert and dilute the entrepreneurial energy of the T.H.A. team members. A better 'selling job' of the venture concept might have helped, but short of geographical separation, it is unlikely that established service departments could have stood aside, perhaps to be eclipsed if the new venture grew to success.

The imposition of the matrix type structure on top of the venture structure of the T.H.A. project was the most fundamental intrusion by the existing organization. Essentially, the venture group should have been completely self-directed. A single linkage with the parent company could have been tolerated but the multi-linkage system proved to be unworkable.

4. Reluctance to give venture group members freedom of action. The problems concerning buying have already been mentioned. There was also a tendency for staff to be drafted to the projects by the Engineering Group management without consultation with existing team members. In the area of finance, although budgets were agreed and allocated, the project leader was required to obtain authorization for relatively small expenditures. The effect of these interferences was to blunt the enthusiasm of the team.

5. Tendency for mechanistic forms of operation to be created within the venture group. The chosen venture managers who headed their groups had gained their experience largely within the parent company. It was not surprising, therefore, that they tended to develop their groups along traditional lines. Hanan (95), Gardner (96) and Hill and Hlavacek (97) all indicate that an informal organization with uninhibited communications is essential for innovative groups. Yet the groups set up by Engineering Group soon showed the manifestations of a developing hierarchy - grading of offices, competition for secretaries and a growth of paperwork. Preoccupation with these elements led to reduced vitality in the real work of the project and caused frustration amongst those team members for whom the privileges of power were not available.

6. Lack of real incentive for team members to succeed. In this venture experiment there was no question of financial investment by the team members, to be repaid by high reward when the project became a success. The main incentive lay in the suggestion that if all went well and a good business was created, then the participants would assume positions at a much higher level than they could otherwise have expected. However, another possibility was indicated as the project developed: it would be 'grafted' onto an existing operation and come under the control of a senior line manager. Because no clear indication to the contrary was given, the team members concluded that their prospects were little different from those of any other employees in Engineering Group. They could not then be expected to work harder or with more enthusiasm than normal.

Of these six conclusions, this last one concerning the need for real incentives is considered by the writer to be one of the two most important factors in determining the success of a venture exercise. Whether the incentive is by bonus payments, equity participation or some other means, the prospect of relatively enormous personal gain is essential if extraordinary performance is required.

The other important factor is the need for geographical separation to keep the organization of the parent company from meddling in the venture operation.

The writer's observations of the Engineering Group experiment have shown that on-site venture operations are too easily treated as just another part of the existing organization.

CHAPTER 7

CONCLUSIONS FROM THE STUDY

7.1 Introduction

In this final chapter, conclusions from the different aspects of the work are presented and discussed. The implications of the findings - both for Engineering Group and for other organizations undertaking product innovation - are analysed and related to other published research.

One of the problems of reporting multi-disciplinary research is the difficulty of showing the interrelationships whilst maintaining clarity and avoiding excessive repetition. It has been decided that the conclusions from the study are best presented in the format adopted in Chapters 4, 5 and 6. Hence the results of the technical, marketing and organizational work are discussed in three separate sections which follow this introduction.

The implications of the results for Engineering Group and other organizations are then discussed in two further sections. By presenting the conclusions from the study in this way, the writer hopes he has provided a satisfactorily homogenous completion to the Thesis.

7.2 Results of the Technical Analysis

During the development of the T.H.A. from the original concept to a pre-production prototype a need arose for more comprehensive technical data than already existed. Also a number of specific problems were encountered. By using a systematic approach, satisfactory solutions were obtained in each case.

1. Hose Characteristics. The original motivation for this work was the need for the writer to provide himself with a thorough knowledge of a new project. It was soon clear that this work was an essential pre-requisite to the market assessment work that was later undertaken. For example, knowledge of the rotational behaviour of hoses at different pressures enabled estimates of the eventual size of the actuator to be made. Hence comparison with existing competitors' products was made possible.

To have attempted an investigation of the market without a clear understanding of the properties of the proposed product would have been as valueless as if the market study had not been carried out at all. This was a view noted by Debreyne (98) in his discussions of the factors leading to the success or failure of new products.

2. Theoretical Analysis of Hose. The intention behind this work was to find a way of predicting the characteristics of different sizes and constructions of hoses other than those which were readily available for experimental work. An examination of technical literature, followed by additional analysis, resulted in the torque behaviour of the hose being described by a mathematical expression which took account of a number of special features of the hose. These features had been ignored in an earlier analysis undertaken at the Research Centre.

Nevertheless, when the theoretical results were compared with experimental results, unsatisfactory correlation was observed. It was reluctantly concluded that, with the resources available, it would not be possible to produce a completely satisfactory analysis. This confirmed the limited value of theoretical data in rubber engineering - a view frequently endorsed by colleagues in the Industry. The behaviour of rubber compounds varies erratically in a complex, non-linear fashion. Rivlin & Saunders(99) acknowledge that even apparently identical rubber test pieces can have significantly different properties. This has important consequences for new product work in Dunlop.

3. Development of Hose End-Fittings. This part of the project highlighted many problems typical of those which have to be faced in the course of most technical developments. In seeking to develop a satisfactory end-fitting, many blind alleys were followed before an effective design evolved. Each time a line of work was abandoned, it was necessary to be reconciled to the fact that much patient effort had been in vain. As noted in Chapter 4, co-ordinating and directing this kind of development work requires special skill and maturity. In particular, the ability to maintain enthusiasm - even after several failures - and the ability to make bold decisions in order to use resources most effectively.

Also during this work, some problems were encountered which were a consequence of being located within a large, divisionalized company. Part of the end-fitting work was undertaken by the Research Centre because special facilities were available there. Despite the great care taken in co-ordinating that work with the Engineering Group work, the writer was not always able to maintain the degree of relevance he desired. For example, test procedures were not always identical to those used at Engineering Group. Work tended to continue after a 'stop' decision had been taken and notified. Progress at Research Centre was sometimes erratic depending on interests and commitments. Development work at a single location would have been quicker and more effective.

The expectation that full use should be made of internal resources in preference to those outside the company was a further problem. In seeking advice and products from other Dunlop divisions, the sort of rapid attention normally expected by potential customers was not always enjoyed by the T.H.A. project. For example, the long delay in supplying hoses by the Dunlop Subsidiary was probably caused by that division's decision to treat the order as an internal one - priority being given to external orders. Inter-divisional rivalry might also have been significant - the extent of its existence and its effects would make a challenging study.

Once again, the special difficulties arising from the nature of rubber compounds were noted. The cure-bonded end-fittings, where inter-molecular linkage between rubber and steel was involved, produced a bewildering scatter of results when fatigue tested. This experience, together with the problem of non-linearity of mechanical properties discussed in the last section, suggests that any development work with rubber must be viewed as a long term exercise. Confirmation of the behaviour of new rubber products may require many months or years of repetitive testing - a point highlighted by Moulton (100) in a report on the "Hydrolastic" development.

A conclusion of more general validity concerns the need for caution in the use of substitute test procedures. There is a wide appreciation of the potential dangers, for example, in accelerated life testing of prototypes (a discussion by Buck (101) is representative). In the present case, the decision to adopt an alternative test procedure led to the production of erroneous data. This was detected when results from the original and substitute procedures were compared. Had this comparison been overlooked, the product might have been credited with a totally misleading specification - which would not have been discovered until dissatisfied customers reported failures.

4. Improvement of Life of Hose. The discovery that the durability of the hose was not nearly as good as was required, led to a most interesting phase in the project. This unanticipated problem was typical of those which occur in development programmes - and after analysis, a satisfactory solution was found. However, the problem was viewed by Engineering Group Management as a major set-back. Rather than firmly support the project during a difficult period, it was decided that part of its work force should be transferred to another project where there was an apparently greater chance of success.

It is a necessary part of the function of all managements to take this kind of decision; successful businesses depend on sound judgement in these matters. On the other hand, speculative work requires perseverence and consistent top management support - a view noted by Mueller(102) and others. Even when a solution to the life problem had been found, it was impossible to regain momentum. The lesson seems to be that acknowledgement that problems will occur should be made when a project is initiated; and an indication should be given of the degree of uncertainty and set-back which can be tolerated. Perhaps this might be defined in terms of a limit of expenditure that may be incurred before formal review is required.

In tackling the problem of the life of the hose, a dual approach was used by the writer. First, he referred the problem to the Research Centre where a series of 'quality control' measures at the manufacturing stage were proposed which, it was thought, would help improve the durability of the hose. The writer felt that a more fundamental change in the hose design would be required, so he undertook an independent analysis of the problem.

Proceeding from a review of the literature on fatigue life problems in rubber, he formulated the hypothesis that alteration of the amounts of rubber and steel cord in the hose would have an effect on the working life of the hose. By testing a series of specially built hoses, it was found that there was an optimum rubber/steel ratio which gave a maximum fatigue life. Further testing gave additional results which confirmed the findings. These results may have wider validity than for Torque Hoses alone. Similar relationships between cord spacing and fatigue life may exist for other reinforced rubber structures which are subject to cycles of pressurisation. Hence these results will be of interest to those engaged in the design of reinforced rubber products.

For the reasons discussed in Chapter 4, it was decided that hoses with the optimum design would not be specified. This decision was taken as soon as test results were showing a clear trend - for the purpose of this project it was considered that further confirmatory results were unnecessary and that effort would be best directed to other aspects of the project. In fact, the writer was allowed to complete sufficient tests to satisfy himself that the pattern of results was consistent.

This is an example of the way that a product development project can spawn a research project which may then have wider relevance. Clearly it may not be satisfactory to devote development resources to research after the immediate needs of the development project have been met. In such cases, a mechanism is required that will enable the research work to be transferred to, or brought to the notice of, an appropriate department. In Dunlop such a mechanism does not seem to operate. Information was supplied to the Research Centre but no indication was received that the results of the research had been noted or transmitted to sections likely to be interested, e.g., Hose Divisions within the company.

7.3 Results of the Marketing Analysis

The Torque Hose Project was presented to the writer as a technical exercise, but it was soon clear that marketing information was required to ensure the relevance of the technical work. Within Engineering Group, marketing activities were on a small scale. A two-man Corporate Planning department provided senior management with general strategic information and various advertising and publicity departments supported the sales effort. But no market research department was available which could undertake exploratory work or provide statistical information. In an operation the size of Engineering Group, quite heavily committed to new product work, this must be seen as a weakness in the organizational design.

It may be argued that the earliest work on the project had been inappropriate because the product application which had been selected did not have sufficient market or turnover potential. This line of development was abandoned because of technical problems, but only after the expenditure of many man-hours of work. An expert market assessment probably would have rejected this application at an early stage and then would have provided information to show the potential of alternative applications. Thus, marketing awareness and expertise might have ensured greater productivity from the technical effort.

1. Evaluation of Secondary Data. A preliminary market analysis was carried out by the writer as a familiarization exercise. This involved an inspection of competitors' products at exhibitions, an examination of their technical literature, a consideration of the different applications of pneumatic actuators and a rough estimation of the general size of the pneumatic business. This brief analysis suggested that the Torque Hose was best considered as the basis of a general purpose rotary actuator rather than a device for performing a specific task, such as the 'bus door actuator previously proposed. To confirm this view, and to assess the potential of the T.H.A., further 'desk' research was undertaken.

A careful study of competitors' products demonstrated that the T.H.A. would be satisfactory in terms of performance, size, price, etc. In order to reach this conclusion, some basic information about the properties of the Torque Hose was required together with some judgement of the prospects for their modification through development. This indicates the advantage of encouraging an individual or a single group to investigate both technical and marketing features. Burns & Stalker (91) found that companies organized this way tended to be successful with their new products. Communication problems, which occur where marketing and engineering are separate functions, are eliminated; similarly by having an appreciation of the features of the market, the development engineer is able to avoid the incorporation of unsatisfactory features into his own product. This leads to efficient development work - found to be highly important by Project SAPPHO (39) in its investigation of success in innovation.

2. Estimation of Value of Market. From published statistical information, it was possible to estimate the total annual value of sales which the T.H.A. might achieve when established in the U.K. market. An exact figure could not be derived, but it was found that a possible range between upper and lower estimates could be deduced. Although this range was broad, it was sufficient to indicate that the T.H.A. was probably worth developing by Engineering Group - perhaps as one of a group of products with similar turnover potential. The writer felt that further confirmation was required of the potential sales figure. However, an organizational change, which coincided with the 'formal adoption' of the T.H.A. by Engineering Group, took place before more analysis could be started.

No further research work was carried out into the value of the market. There was a tendency for opinion to supplement the basic data already provided, with the result that the prospects of the project became artificially enhanced. Later, a check of the writer's work in the light of up-to-date technical data forced a realistic view of the sales potential. Compared with the artificially high figures, this then seemed quite poor and interest in the project sharply diminished.

Thus, because of a lack of marketing awareness the project was alternately encouraged and ignored, depending on the strength of opinion and circumstance. Confident marketing work from the earliest stages of a project would prevent this inhibition of progress from occurring.

3. Identification of Customer Requirements. Whilst statistical data gave an indication of the size of the market and the nature of competing products, it gave little information about the needs of customers. Before any serious product design work could be started, a knowledge of customers' special and general requirements was essential. Since Dunlop was not yet active in the market, no information was available internally. After consideration of the problem, it was decided that some practical market research should be undertaken. By probing companies' current purchases of pneumatic actuators, it was expected that knowledge would be obtained about features such as durability, particular applications, most common sizes, etc.

Although a pilot survey was carried out, the full scale exercise was never started. The reason for this was a Management decision that Engineering Group would manufacture the actuator but, rather than set up a sales organization of its own, it would license one or more companies to sell the product. It was argued that all data necessary for the further design and development of the T.H.A. would be available from these companies. Two companies were courted as potential distributors and market information was sought from them in exchange for Engineering Group's disclosure of the product concept.

The consequences of this policy decision have been discussed in Chapter 5, but it is appropriate that a general conclusion should be reached at this point.

In an organization like Dunlop which has several centres of innovation, it is likely that new products like the T.H.A. will emerge fairly frequently. In some cases, the new product will not logically fit into the company's scheme and, often, the best way of deriving a benefit will be disposal under a licence, either total or partial, i.e., like the T.H.A., selling rights but not manufacturing rights.

A major difficulty lies in the timing of disclosure of the new product to suitable external organizations. Of necessity, this may have to be done before development of the product is complete. If the developing company lacks experience of the product, it will not want to run the risk of perfecting features that the recipient company will view as unsatisfactory. But if disclosure is too early, the recipient company may be tempted to instigate a rival product based on the disclosed product. Thus, in the case of the T.H.A.,'Company B' began to work on a similar product whilst continuing to express a token interest in the original product.

Another problem of early disclosure is that the recipient company will resist (quite rightly) entering into any formal licencing agreement until the nature of the new product is completely clear or until the time seems right to add the product to its range. The recipient company will not wish to pay royalties or a fee for a licence unless it is ready to make immediate sales of the product. So, in its relations with the developing company it will tend to stall in discussions on the agreement in the hope that the development of the product will continue. At the same time, it will avoid disclosing too accurately its own assessment of the commercial prospects for the product or offering more details about its own field of business than it would normally disclose to another company.

The writer's conclusion is that the two issues - of obtaining information about customer needs and of organizing the granting of product licences to other companies - should not be confused or combined. In developing a new product, a sound knowledge of the customer's requirements and preferences is essential; if necessary, market research techniques should be used. Then, if it is decided to dispose of the product under licence, it will be possible to negotiate from a position of strength. Thus, a thorough understanding of the market is equally important whether a product is being developed for normal commercialization or for disposal under licence to another company.

7.4. Results of the Organizational Analysis

Whilst the Technical and Marketing research work was being undertaken, the organization of the T.H.A. project was changed a number of times. The writer's intimate involvement with the project aroused a desire to analyse and compare the features of these different forms of organization, which were discussed at some length in Chapter 6.

In deriving conclusions from this analysis, one feature stands out which was common to each of the three forms of organization that were studied; the difficulty with which the Product Development operation co-existed and co-operated with the rest of the firm. In the case of the "Product Development Unit" organization, which was self-sufficient in terms of skills and equipment, the problem arose either when new products were ready to be manufactured, i.e., handed over to production, or at the times when the Unit's Director needed to seek financial and moral support within Engineering Group. Similarly, when the T.H.A. project was organized as a 'special project', it was found that other company departments were reluctant to provide the help and facilities which the project required on a day-to-day basis. Finally, when organized as a Venture project, existing functions in the company criticized the methods used and effectively imposed a bureaucratic damper on the product development process.

Many management writers refer to the "Not-Invented-Here" (N.I.H.) factor which is a concise summary of the attitude of many departments when innovative changes from outside are presented to them. It is a natural human tendency to reject ideas simply because they are proposed by someone else. In Engineering Group, the problem seemed to be more serious than this. Not only was a passive resistance to new product work observed, characterized by a lack of interest and co-operation, but also an active resistance was encountered. This took the form of sustained criticism of methods and approaches, imposition of restrictive systems and the application of cumbersome appraisal techniques.

There is no reason to believe that this problem is unusual and in any way peculiar to Engineering Group. It has been mentioned already that both Schon (12) and Ben Daniel (44) draw attention to the problem. The important point is that rejection of the results of new product work can occur even in organizations which, apparently, are committed to a policy of innovation.

Another point of concern observed in each form of organization was the distracting effect on innovative work of political conflicts. It would be naive to expect that political conflicts or personality clashes will not occur in industrial organizations as in every other form of social activity. But the writer now believes that the extent of such conflicts and their effects can be aggravated by the use of certain organizational forms. For example, when a matrix system was applied to the T.H.A. project this had the effect of dividing the project team (small as it was) into two camps over certain issues. This 'reinforcement of politics' effect must be seen as a serious disadvantage of matrix systems, a point which needs to be considered by senior managers when designing organizations to deal with innovation.

This leads to some conclusions about the role of senior managers and leadership styles. A recognition, as in Engineering Group, by top management of the need for new products to take the place of those which are no longer competitive, implies an awareness of the changes that will be caused by the introduction of those new products. To cope with the changes, writers such as Basil and Cook indicate that certain 'change responsive' qualities are necessary in managers involved in innovation. They list these qualities (Fig. 2.4) and compare them with those of 'traditional' managers who operate best in stable conditions. Observation of the managers engaged in the direction of innovative projects in Engineering Group, suggested that their qualities were largely those of traditional managers. For example, the tendency to be role-oriented rather than goal-oriented and the tendency to operate formal procedures, were features of the Venture group leaders. It is necessary for the most senior managers in a company to understand the special nature of product development work and to select project leaders with appropriate aptitudes, experience and training for innovative work. The writer found that, in Engineering Group, the organization was generally rigid and hierarchical; top management were remote both physically and spiritually from the basic activities of the enterprise. The project leaders perpetuated this style of management.

In his investigations, Langrish (40) found that the presence of 'an outstanding person' was one of the main factors in achieving successful technological innovation. This claim is substantiated by Pelz (33) who stresses the importance of high quality leadership. In contrast to the later Venture projects, effective leadership was observed in the earlier operation of the Product Development Unit. Here, the Director was a man of sensitivity and character who was always involved in the daily activities of his department and encouraged participation as far as possible. The result was effective and dedicated development work.

7.5 Implications for Engineering Group and Dunlop of the Results of this Study

Several points, of special interest to Engineering Group and other parts of Dunlop, have arisen during the course of this project. Most of these have been noted already in the preceeding sections of this chapter but it is felt that they should be brought together at this point.

1. T.H.A. Development Work Successfully Completed. Engineering Group's main requirement of the T.H.A. project was that a successful new product should be created. At the time of writing, this has not been achieved - the eventual success or failure of the new product will not be known until after licencing negotiations are concluded. However, it may be stated that the technical work of the project has been completed to a degree considered satisfactory in Engineering Group. During a period of 2½ years, the writer (together for a short time with his Venture team colleagues) tackled a number of technical problems. In the light of marketing information, successful solutions to the problems were found and extensive design work was completed. The culmination was a prototype actuator (Fig 3.6) which forms the focus of the licencing proposals. To complete the project, a report (66) containing full up-to-date information about the T.H.A. was presented to, and accepted by, Engineering Group management.

2. Use of Rubber in New Products. Many of the technical difficulties encountered were a consequence of the unpredictable nature of the mechanical properties of rubber. In developing a rubber product like the T.H.A., it is necessary to undertake extensive and lengthy product tests. This means that the development time for rubber products can be much greater than for products which are built with materials whose properties can be investigated theoretically with great certainty. In Engineering Group there is an expressed need for a fairly rapid introduction of new products. Hence, products like the T.H.A. are not the most suitable choices in these circumstances. Indeed, it is noticeable that the most recent innovative projects in Engineering Group appear to be the result of an acknowledgement of this conclusion. Products which have been selected for development, all feature an existing high level of technical knowledge. Rubber products have been avoided.

3. Inter-Divisional Relationships in Dunlop. These appear to need some examination. Whilst divisions operate autonomously as separate business units, strong attempts are made to maintain the corporate "Dunlop" identity. Throughout the course of the T.H.A. project, the writer was urged to use internal resources as far as possible. However, in practice he found that the co-operation of other

divisions was difficult to obtain. Possibly because of inter-divisional rivalry, service and advice was frequently obtained much more slowly from within Dunlop than from outside companies. A properly structured investigation into divisional policies and attitudes to other parts of the company would provide Head Office management with much vital information for use in the formulation of company policy. Important parts of the investigation would be (a) an examination of the mechanisms by which information passes between divisions and (b) the relationship of the Research Centre to other divisions and their innovative activities.

4. Approaches to New Product Work in Engineering Group. Over a number of years, new product work has been undertaken in Engineering Group but only limited commercial success has been achieved. At top management level there has been no lack of understanding of the need to innovate and this has been supported by investment of funds and much hard work at all levels. A 'strategic gap' between expectations and achievements has been experienced and at least two of the six possible causes which were discussed in Chapter 2 have been involved.

(i) Environmental scanning deficiencies. The major problem has been a lack of marketing expertise and a failure to view the innovation process as one of 'industrial commercial development' (19) i.e., matching real needs with new technology. The needs of markets have not been properly analysed when starting development work, with the result that great efforts have had to be used subsequently to convince unwilling markets to purchase the new products. The reason for this is that Engineering Group has historically viewed marketing simply as a 'selling' process - not as an information-gathering process. The introduction of marketing executives, some with Business School training, is an encouraging sign but there is still a marked reluctance to use the information which they can provide. A general awareness of marketing philosophy and techniques as applied to new product work should be seen as an urgent priority - a programme of suitable management training courses might be a satisfactory starting point.

(ii) Organizational inflexibility. For Engineering Group, this is just as serious as the 'marketing awareness' problem. The rigid, hierarchical management system, which has developed around the various production processes, is not suitable for innovative work. Yet, in Engineering Group, such systems invariably evolve whenever a product development group is set up. The consequent rigidity and stratification discourages the emergence of any concept of working towards a common goal. The benefits of multi-disciplinarity are lost as team members work without enthusiasm at their allotted tasks while senior team members become preoccupied with the development and maintenance of an organizational hierarchy. They are encouraged in this by the influence of the main company organization which seeks to perpetuate a conformity - regardless of the fact that external changes in the market place render such conformity dangerously inappropriate.

These problems of organizational design and style of management were discussed in Chapter 6 during the examination of the various systems applied to the T.H.A. project. A number of conclusions were reached towards the end of that chapter from which the following points arise of particular interest to Engineering Group.

(a) As implied in the last few paragraphs, performance in development projects to date, suggests that close attention needs to be paid to the form of organization encouraged. The aim should be to move towards a goal-centred 'organically' structured system.

(b) To achieve this aim, the question of motivation and incentives for success of all participants needs to be considered. The degree of success achieved in product development is the primary factor which influences the prosperity of the firm. This should be reflected in awards for effort and achievement.

(c) Special care needs to be taken in the selection of senior staff for development projects.

In particular, 'change responsive managers' are required. It is unlikely that such managers will be found within the existing 'mechanistic' organization of the company.

(d) In order that development projects with flexible organizations should stand a chance of flourishing, it is essential that some real protection should be given from the bureaucracy of the rest of the company. To achieve this, geographical separation may well be the best solution.

7.6 Relevance of the Results of the Study for Other Firms

The results of the technical and marketing analysis are chiefly of interest only to Engineering Group and to companies that are subsequently granted a product licence to exploit the T.H.A. An exception to this generalisation concerns the information discovered about the effect of the spacing of reinforcements on the fatigue life of composite rubber-steel cord structures.

Of more general interest, will be the aspects of the Thesis which present a 'case-study' account of the development of the new product. Also, the organizational conclusions which have been derived specifically as relevant to Engineering Group and Dunlop will have validity in other companies. Indeed, it has been the writer's intention that the wider application of the development project should be apparent throughout the Thesis. Taken with the results of other studies, it is hoped that a better understanding will emerge of the nature of new product development - and consequently that the success rate of innovative projects will be improved. Hence, the following summary is presented of the most important general conclusions from the study. The intention has not been to attempt to define a standard prescription which will ensure constant success in product development work - but to highlight those aspects which need special attention because of the extent of their influence on the outcome of innovation.

1. There must be an understanding of marketing techniques within the firm and a willingness to use marketing information.

2. Technical work must be related constantly to information about the potential user's needs.

3. Consistent top management support is necessary throughout the development process.

4. A flexible goal-oriented form of organization must be achieved; rigid hierarchies must be avoided.

5. Development projects may need to be protected from the bureaucracy of the rest of the company.

6. Adequate incentives need to be offered to all employees who are involved in product development work.

7. Particular attention must be paid to the personal qualities of those in charge of development projects. Outstanding projects usually have outstanding leaders.

APPENDICES

APPENDICES - A NOTE OF EXPLANATION

The Appendices are copies of 4 technical reports issued in Dunlop by the writer. It will be observed that they contain a mixture of Metric and Imperial Units. This is a reflection of the common practice which operated within Dunlop during the course of the project. In the main body of the Thesis, Metric units have been adopted as standard but it has been decided that the Appendices should be presented without amendment.

This prompts one further conclusion from the study : the prolonged and indecisive transition from Imperial to Metric units is the cause of considerable inefficiency and expense in Industry. Dunlop has a good record of Metric standardization but old traditions live on and expensive equipment cannot be replaced instantly. Many of Dunlop's suppliers seem to insist on continuing the use of Imperial measurements - on several occasions the writer prepared engineering drawings using Metric units only to discover that the first action of sub-contractors had been to convert all dimensions into Imperial. In the process, errors invariably occurred and subsequent work was needed to correct faults.

There is a need for urgent action to tackle this problem on a national basis ; British Industry can do without the handicap of a dual system of units.

APPENDIX 1 - COPY OF REFERENCE 75

TORQUE HOSE PROJECT - TECHNICAL REPORT

FATIGUE LIFE OF HOSE

A hose has been developed using a rubber compound containing 50% Natural Rubber and 50% Neoprene. This compound was selected because it offers good resistance to ozone cracking and to oil attack. A number of hoses were regularly tested to 100,000 cycles on a rig at Research Centre. Since there was an understanding at Research Centre that 100,000 cycles was a satisfactory life, only a few hoses were cycled further. Several hoses did reach 250,000 cycles, some as far as 400,000 before failure. In the light of this information, we, at Coventry, anticipated being able to achieve 250,000 cycles regularly.

However, we have found that life of only 80,000 to 100,000 cycles can be obtained using short lengths of hose and 250,000 using longer lengths of hose at lower pressures than at Research Centre. Our rig cycles much faster than at Research Centre and applies torque throughout the cycle, not just at the end.

From this brief and unscientific report of testing, an important point does emerge. Using our present hose, we may only be able to be sure of specifying lives of

80,000 to 100,000 cycles for the most severe form of use for the hose, i.e. high pressure, short length, high cycle operations. The question which must be asked is can we expect to extend this life and if so, by how much ?

1. Fatigue Limits

It has been estimated (1) that when the diameter of our hose increases by 50%. the rubber between the cords is extended by 100%. In an article by G.F. Lake (2) tensile fatigue life is discussed for various rubber compounds : at a strain of 100% results of between 100,000 and 500,000 are reported, with Natural Rubber performing better than most synthetics. As strain increases to 200% then performance falls to between 10,000 and 100,000 cycles - our short lengths of hose were showing a diameter increase of nearer 100% than 50% and so the inter-cord rubber would be straining by up to 200%. thus explaining our short (80,000 to 100,000) cycle lives. According to Lake, in crystallising rubber (such as Natural Rubber and Neoprene) crack growth and subsequent failure depend on the number of cycles but not on time. This means that the frequency of cycling should not affect the life of the hose. However, he later makes the point that crack growth does increase with temperature and it is our experience that increased rates of cycling cause heat to be generated in the hose.

The conclusions from this are :-

1.1 Whatever rubber we use, the best performance we can expect at a strain of 100% is 500,000 cycles. At a strain of 200% the figure is 100,000 cycles.

1.2 If we reduced the number of cords in the hose, the amount of rubber between the cords would increase. So, for a given increase in diameter, the strain in the rubber would be reduced. If it was reduced to 75%, or so, the increase in life could be dramatic (up to 2,000,000). The objections to doing this are :-

a) Special cord preparation would have to be made - at present we use a standard preparation.

b) The stress in the remaining cords would be increased, perhaps unacceptably.

2. Effect of Torsional Strain on Fatigue Life

In addition to the simple tensile strain caused by the inflation of the hose, there is also a fatigue effect caused by the rotation of the torque hose. Davey & Payne (3) give some information on this, showing that for a small test piece subject to cyclic angular strain of between 26° and 38°, the fatigue life was between 1,000,000 and 100,000 cycles respectively.

For the torque hose, one would expect the effect of the angular strain to be very unimportant compared with the inflation strain except in the case of very short hoses. For example, recent tests using a 5" long hose with 90° of rotation means that the peak angular strain is about 30° per inch of length (approximately 1" at each end of the hose to be fixed by the end fastening - hence all rotation occurs in the middle 3"). A series of tests would be required to quantify the relative fatigue effects of inflation and rotational strain.

3. Fatigue Improvement by Non-relaxation

Referring again to Lake's work it was seen that great improvement in fatigue life could be obtained by preventing the rubber from completely relaxing during the strain cycle. It seems the reason for this phenomenon is not totally understood but is thought to be caused by crystallisation of the rubber which acts as a 'crack-stopper'.

To exploit this phenomenon in the Torque Hose we would need to design a hose assembly so that a pressure always remained in the hose at the end of each cycle. The evidence suggests that we could obtain 5M+ cycles this way.

4. Effects of Creep

Rubber components which are subject to a load will gradually creep. There are two components to the process - a physical effect which is important at short times and is not dependent on temperature and, a chemical effect which is proportional to time and is strongly influenced by temperature.

My understanding of the phenomenon is that the rate of creep is likely to be between 2% and 7% depending on the compound used. These values should not cause us any problems since the hose attachments must be designed to accommodate much larger deformations as a matter of course.

There seems little point in continuing our creep test with an inflated hose at room temperature ; results will not be measurable for several years. Allen,Lindley and Payne (4) make the point that there is no single accelerated test which will enable the behaviour at long times to be accurately predicted. Measurements must be taken over a range of temperatures so that extrapolation to the working temperature may be made. It is obviously outside the limited scope of the Torque Hose Project to start a programme of testing like this - but creep information on our compounds might be available from Research Centre or elsewhere.

CONCLUSION

There seems to be a good chance that we can improve the fatigue life of our hoses by:-

a) Reducing the maximum strain in the inter-cord rubber

b) Exploiting non-relaxation of the hose to boost the fatigue life.

M. H. OAKLEY

References

(1) J. A. Jenkins Central Research and Development Division Report TRR 463 (February 1973)

(2) G. J. Lake 'Working Life of Rubber Components' in Rubbers Handbook ed. L.R. Mernagh (Morgan-Grampion 1969)

(3) A. B. Davey & A. R. Payne 'Rubber in Engineering Practice' (MacLaren 1964)

(4) P. N. Allen, P, B, Lindley & A. R. Payne 'Use of Rubber in Engineering' P R (MacLaren 1967)

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APPENDIX 2 - COPY OF REFERENCE 76

TORQUE HOSE PROJECT

EXTENDING FATIGUE LIFE BY REDUCING STRAIN

In the notes on fatigue life of Torque Hoses (29 March 1977) I suggested that an improvement in life might be obtained by reducing the number of steel cords in the hose, thus reducing the strain in the intercord rubber. I now have more information on this and can estimate the maximum improvement which might be obtained.

1. Existing Construction and Fatigue Life

The cord prearation which we use is supplied by Fort Dunlop and is identified as P669. From published information on this preparation (1) it is found that it contains 98.5 cords per 100 mm (25 per inch) and that each cord has a diameter of 0.63 mm. This means that for any length of the preparation, 62% is inextensible steel and 38% is rubber. The consequence of this in terms of fatigue life (2) for given increase in diameter of the hose are :-

Increase in Diameter	Strain in Intercord Rubber	Probable Fatigue Life
50%	132%	100,000 cycles
100%	264%	40,000 cycles

In fact, our fatigue performance has been better than this possibly because the layers of rubber outside and inside the cord layer enable the hose to function for a time after the rubber between the cords has failed.

However, we can use the figures above to compare with estimated cycle lives of hoses containing fewer cords and more rubber, to give an idea of the order of magnitude of improvement that might be achieved.

2. Calculation of Minimum Number of Cords per Inch Consistent with Acceptable Value of Cord Tension

The steel cord specification (3) states a minimum breaking force per cord of 83lb f (390 N). In earlier work (4) a safety factor of 4 : 1 was adopted so the maximum tension allowed in the cords used in torque hoses is 20lb f, say. In the same report the following relationship is derived :

$$n = \frac{Pr}{f \sin^2 \alpha}$$

where n = number of cords per unit length
P = air pressure in hose
r = radius of cords
f = maximum tension per cord
α = angle of cord relative to hose axis.

For a 2" diameter torque hose

Pmax = 120lb/sq"
r = 1"
f = 20lb
α = 54° $\sin^2$ = 0.655

Hence

$$n = \frac{120 \times 1}{20 \times 0.655} = 9.2,$$ say 10 cords per inch, 40 cords per 100 mm

3. Construction With 10 Cords per Inch and Fatigue Life

The proportions would now become 25% steel cord and 75% rubber. Referring to the same fatigue information (2) as before, the consequences are :

Increase in Diameter	Strain in Intercord Rubber	Probable Fatigue Life
50%	67%	1,000,000 cycles
100%	134%	100,000 cycles

4. Objections to Reduction in Number of Cords

The expectation of improved fatigue life has been based on the assumption that for a given torque and pressure, the increase in diameter of the hose will be the same for a reduced number of cords. Clearly, with a greater proportion of rubber there will be a tendency for the hose to dilate further under pressure - this is why I spoke of estimating the maximum improvement at the beginning of the paper. Probably we could achieve an intermediate improvement, but a series of experiments would be needed to check this. It is interesting that in a paper on the theory of corded tyres, a similar problem, Day and Gehman (5) say that changes in radius and the number of cords are a function of pressure but not necessarily proportional to it.

A practical objection lies in providing alternative cord preparation for the torque hose. The existing preparation is available without problem but it seems unlikely that an alternative is available from the standard range.

M. H. OAKLEY

References :-

(1) Fort Dunlop Process Issue - P669/2 (23 September 1975)
(2) G. F. Lake P.15 'Rubber Handbook' ed. L. R. Mernagh (Morgan-Grampion 1969)
(3) Fort Dunlop Steel Cord Spec 21/2 (Tyre Textile Lab, 1 January 1975)
(4) J. A. Jenkins Dunlop Research and Development Report TRR 463 (12 February 1973)
(5) R. B. Day & S. D. Gehman, Rubb. Chem and Tech Vol 36 P.11 (1963)

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APPENDIX 3 - COPY OF REFERENCE 77

TORQUE HOSE PROJECT

INTERIM FATIGUE TEST REPORT

1. Introduction

This report gives details of the results obtained to date following the action agreed at meetings at Research Centre on 2nd May, 1977 and 27th May, 1977. The problem discussed at these meetings related to the short fatigue lives then being obtained at Coventry (50-80,000 cycles) with 6" lengths of 2" diameter torque hose operating through 90°. It was required to boost this to at least 250,000 cycles. It was decided to experiment as follows :

1. Research Centre would make hoses with non-standard cord spacings to see if the increase in rubber/steel ratio would improve fatigue life. (2nd May, 1977)

2. Hoses would also incorporate several overlapping thin layers of rubber on each side of the cord layer instead of a single thicker layer. By having staggered joints in this way, splits caused by the air pressure might be eliminated. (2nd May, 1977)

3. Tests would be carried out with a restrictor in place to prevent excessive dilation of the hose. (27th May, 1977).

4. Hoses would be cured for 45 minutes only. (27th May, 1977).

5. A 0.5 mm thick layer of a natural rubber compound would be placed between the cord layer and the inner liner of 1621 compound to provide a modulus gradient. (27th May, 1977).

6. Non-standard cord preps would be made at Research Centre using as high consolidating pressures as possible. (27th May, 1977).

7. Some test hoses would be built using 1685 compound (natural rubber) instead of 1621 compound. (27th May,1977).

8. Hoses would be cured using airbag pressure of 350-400 psi instead of the usual 160 psi. (Agreed after the two meetings).

2. Equipment

The following equipment is available at Coventry for fatigue testing of hoses :

(i) End-load rigs (three) designed to allow 90^{o} or greater rotation of the free end of the hose. Full torque then developed at the end of the rotation. Rotation not assisted on return.

(ii) Constant load rig (one) designed to allow 90° or greater rotation. Resisted by a constant load during the forward rotation and assisted by a similar load on the return rotation. Rig simulates the conditions of operation of a single-acting spring-assisted return torque hose actuator.

3. Testing Programme and Results

The following tests were carried out after the first meeting (2nd May, 1977).

1. Hose No. 68. Standard hose 98.5 ends/100 mm cord spacing. End-load rig. No restrictor. 51,326 cycles before burst. Torque 32 lb.ft maximum. Increase in diameter 54% maximum. This was the 'control' against which to compare the non-standard hoses.

2. Hose No. 75. Cord spacing 104 ends/100 mm. (Cord prep. made by Textile Dept. at Research Centre). This spacing almost the same as the standard prep (in hose No. 68)produced by Tyre Division. End-load rig. Less than 8,400 cycles before burst. Torque 38 lb.ft maximum. Increase in diameter 65% maximum.

3. Hose No. 78. Cord spacing 64 ends/100 mm. (Made by Textile Dept.) End-load rig. 15,626 cycles to burst. Torque 40 lb.ft maximum. Increase in diameter 72% maximum.

These tests were clearly failing to give an improved cycle life for the hose - precisely the opposite effect, in fact. It was concluded that before any benefits of changes in cord spacing could be measured, the dilation of the hose would have to be physically restricted.

At the meeting on 27th May, 1977, it was decided to adopt a number of improvements to the hose construction to help improve the fatigue life (see 'Introduction'). Tests were resumed with the following results.

1. Hose No. 80. Cord spacing 98.5 ends/100 mm (Tyre prep). Built from 1685 natural rubber compound. End-load rig. Restricted to 30% dilation. Torque 12 lb.ft maximum. Test discontinued at 11,774 cycles.
Conclusion - rubber too stiff to allow sufficient torque to develop.

2. Hose No. 76. Cord spacing 104 ends/100 mm (Textile Dept. prep). End-load rig. Restricted to 30% dilation. Torque 22 lb.ft maximum. Burst after 270,654 cycles.

3. Hose No. 85. Cord spacing 104ends/100 mm (Textile Dept. prep). Constant load rig. Restricted to 30% dilation. Torque 24 lb.ft maximum. Burst after 525,000 cycles.

4. Hose No. 71. Cord spacing 98.5 ends/100 mm (Tyre prep). End-load rig. Restricted to 30% dilation. Torque 22 lb.ft maximum. Test still continuing at 600,000+ cycles.

5. Hose No. 77. Cord spacing 80 ends/100 mm (Textile Dept. prep). Constant load rig. Restricted to 30% dilation. Torque 22 lb.ft maximum. Test continuing at 700,000+ cycles.

6. Hose No. 84. Cord spacing 64 ends/100 mm (Textile Dept. prep). Constant load rig. Restricted to 30% dilation. Torque 22 lb.ft maximum. Test continuing at 250,000+ cycles.

7. Hose No. 83. Cord spacing 49 ends/100 mm (Tyre prep modified by removal of alternate cords). End-load rig. Restricted to 30% dilation. Torque 28 lb.ft maximum. Burst after 128,150 cycles.

These results are presented more fully in the table. It can be seen that the use of a restrictor to limit dilation to 30%-35% has resulted in considerably improved fatigue lives. With the exception of hoses No. 76 and 83, lives in excess of 500,000 cycles have been achieved. No. 76 may be explained by the very brief cure time of 40 minutes coupled with the low cure (airbag) pressure of 160 psi. No. 83 was built using a 'doctored' cord prep containing a very low cord count. The removal of alternate cords from the standard prep may well have caused damage or weakness.

In the cases of hoses Nos. 71, 77 and 85 it is difficult to draw any conclusions about the effects of 'improvements' to the hose construction or of different cord spacings. It may be that further tests will indicate improved life with decreased cord count/greater cord spacing but at the moment this trend cannot be confirmed. If an opinion was required at this stage, it would be that it would be best to use readily available standard preps (98.5 ends/ 100 mm) rather than expensive special preps.

4. Further Testing

1. Tests will continue on hoses similar to those described in this report until sufficient results have been obtained to enable fatigue lives to be quoted with confidence and to identify the best method of manufacture of the hoses.

2. Tests are taking place to see if it is possible to produce 'self-restricting' hoses, instead of using metal restrictors. At present, hoses have a narrow canvas strip placed over the buttjoin of the cord layer to overcome the tendency to split under pressure at this point. By changing the dimensions of this strip so that it becomes continuous over the surface of the hose, it may be possible to achieve acceptable torque and rotation with limited dilation. A further beneficial effect on the fatigue life may also be achieved, since the discontinuity in strain levels at the edge of the narrow strip may be the reason for the occurrence of bursts at this position.

5. Conclusions

1. From the tests completed so far, it seems that a considerable improvement in fatigue life of torque hoses can be achived by restricting the dilation of the hose. There is a penalty to pay in terms of reduced torque but

this can be offset by using hoses of larger starting diameter.

2. The effect of changing the cord spacing is not clear but it is certainly small compared with the effect of the restrictor. It probably makes sense to stick with the standard tyre prep.

3. Further results are needed but it seems that lives of 250,000 cycles look certain and that 500,000 cycles or greater are probable.

<u>M. H. OAKLEY</u>

18th August 1977

SUMMARY OF TORQUE HOSE FATIGUE TEST RESULTS

HOSE NUMBER	68	75	78	80 (3)	76	85	71	77	84	83
CYCLES TO FAILURE	51326	8400	15626	(4) 11774+	270654	525000	(5) 600000+	(5) 700000+	(5) 250000+	128150
TORQUE (lb.ft)	32	38	40	12	22	24	22	22	22	28
DILATION	54%	65%	72%	RESTRICTOR FITTED TO LIMIT DILATION TO 30%-35%						
CORD PREP. TYPE	(1) 98.5 ends	(2) 104 ends	(2) 64 ends	(1) 98.5 ends	(2) 104 ends	(2) 104 ends	(1) 98.5 ends	(2) 80 ends	(2) 64 ends	(6) 49.25 ends
STAGGERED JOINTS COVER/LINER	NO	YES	YES	YES	YES	NO	NO	YES	NO	NO
CURE TIME (307°F)	60 min	60 min	60 min	60 min	40 min	45 min	60 min	60 min	45 min	45 min
INTERLAYER BETWEEN CORD LAYER & LINER	NO	YES	YES	N.A	YES	YES	NO	YES	YES	YES
HIGH CONSOLIDATING PRESSURE - CORD PREPS.	N/A	NO	NO	N/A	NO	YES	N/A	NO	YES	N/A
AIRBAG PRESSURE DURING CURE	160 psi	160 psi	160 psi	160 psi	160 psi	400 psi	160 psi	160 psi	400 psi	400 psi
RIG - A : END LOAD B : CONSTANT LOAD	A	A	A	A	A	B	A	A	B	A

NOTES:
(1) 98.5 ends/100 mm - Standard Tyre Preps.
(2) Prep. made by Textile Dept. at Research Centre.
(3) Hose made from 1685 Compound (Natural Rubber).
All others 1621 Compound (50-50 Natural-Neoprene).
(4) Test discontinued - Inadequate Torque.
(5) Test continuing.
(6) Made by removing alternate cords from Standard Tyre Prep.

TEST CONDITIONS:
Free length of Hose (between end fixings) 155 mm ± 5 mm.
Rotation of free end 90° ± 10°.
Frequency of Cycling 12-18 cycles/minute.
Compressed air supply pressure 80 psi ± 5 psi.
All hoses built with 52½° cord angle.
50 mm cord diameter.

APPENDIX 4 - COPY OF REFERENCE 78

TORQUE HOSE PROJECT

FATIGUE TEST REPORT

1. Introduction

This report should be read in conjunction with the Interim Fatigue Test Report published on 18th August 1977 and the Technical Reports published on 29th March 1977 and 4th April 1977. Sufficient fatigue results have now been obtained to test the ideas presented in the Technical Reports. It will be recalled that the object of the exercise was to extend the fatigue life of Torque Hoses. To achieve this, two main strategies were proposed.

(i) to change the cord number and spacing in the hoses to reduce strain levels in the intercord rubber.

(ii) to restrict dilation of the hose (to limit the strain) by using rigid constraints on the outside diameter of the hose.

2. Results

These are presented in the table and graph at the end of this report.

It can be seen that we have improved considerably on the 80,000 to 100,000 cycles previously achieved with 'standard' hoses containing 98.5 cords per 100 mm. This is largely attributable to the use of the restrictor, although it can be seen on the graph that the cord spacing also appears to have a significant effect.

It must be noted that the use of restrictors causes two main problems :-

(i) The torque is considerably reduced, by approximately 50% when dilation is limited to 30%. This can be counteracted by the use of a larger diameter hose. (Torque is approximately proportional to the cube of the diameter so a small increase in size gives a significant increase in torque output).

(ii) The design of the actuator becomes more difficult and expensive if the restrictor is included. It is essential to ensure minimum relative movement between hose and restrictor to prevent rubbing and heat build-up. There is also some loss of efficiency but this is not serious since the reduced torque is matched by reduced air consumption.

The graph of the results indicates that the best cycle life is obtained at around 80 cords per 100 mm spacing and that moving away from this value results in lower performance levels.

Reference to the Technical Report of 29th March 1977 confirms that the fatigue lives obtained at 30% dilation for cord counts of 80+ per 100 mm are similar to those theoretically predicted. For example, at 98.5 cords per 100 mm a life of about 1 million cycles was predicted. We obtained just in excess of 750,000. The results for hoses Nos. 83 and 84 caused some surprise, since with the lowest cord count of all (49 and 64 per 100 mm respectively) it was expected that very high cycle lives would be achieved. This may be explained by :

(i) Particularly in the case of No. 83, the quality of the cord prep. may have been unsatisfactory.

(ii) At these wide spacings there may have been a 'window' effect with the rubber straining more than anticipated between the cords.

3. Conclusions

From a practical point of view as far as Dunlop is concerned the conclusion from the series of tests is clear. Although there are indications that the optimum fatigue performance is obtained using hoses with non-standard cord spacings, the performance of the standard hose with a dilation restrictor should be satisfactory. The problems involved in moving to non-standard cord preps. are very great and it is now recommended that the standard 98.5 cords per 100 mm is confirmed as the most suitable hose.

The results of this work may be of interest to designers of reinforced hoses which are subject to pressure cycling.

It is now intended to test further standard hoses in the course of finalising the design of swaged end-fittings.

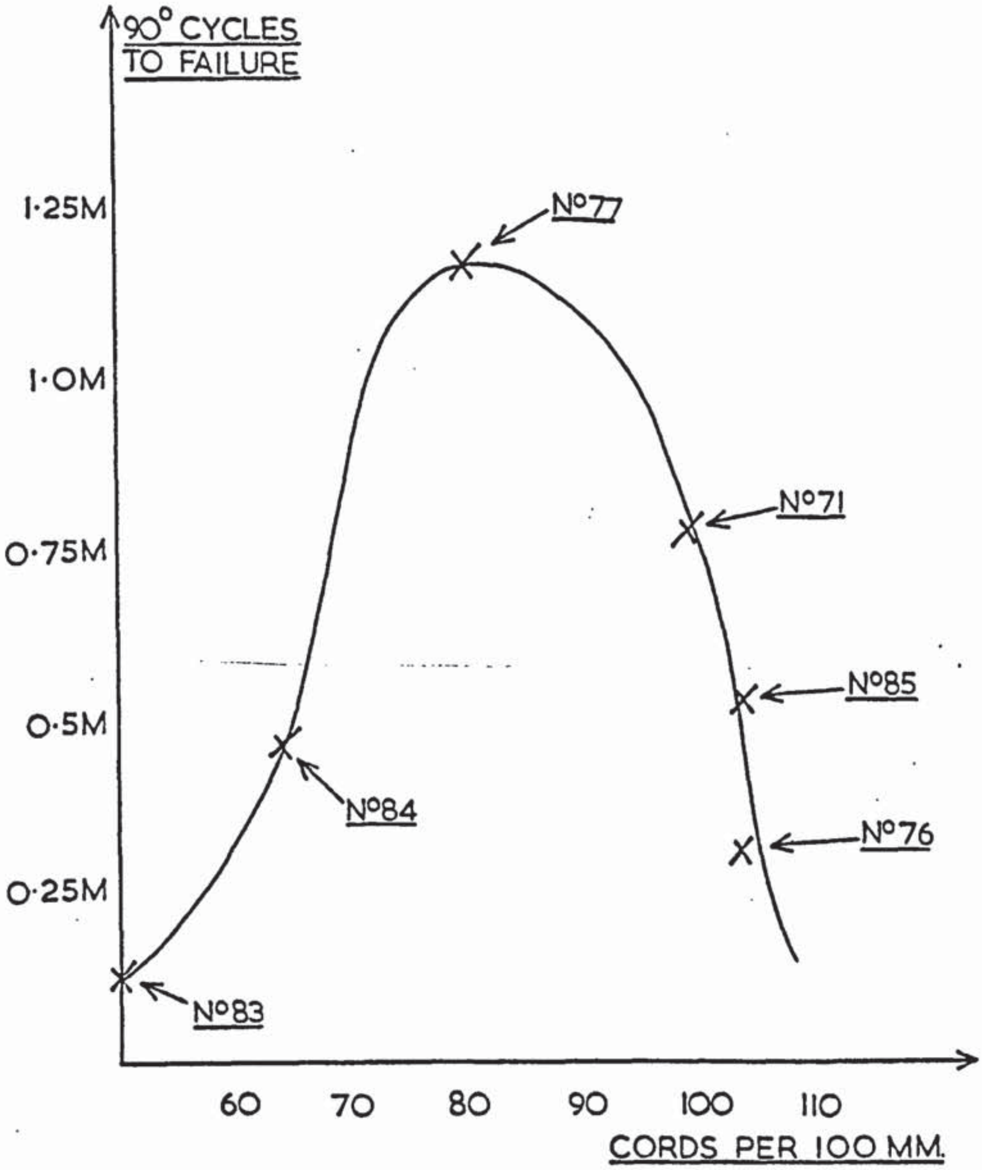
M. H. OAKLEY

SUMMARY OF TORQUE HOSE FATIGUE TEST RESULTS

HOSE NUMBER	76	85	71	77	84	83
CYCLES TO FAILURE	270,654	525,000	756,000	1,174,463	466,184	128,150
TORQUE (lb.ft)	22	24	22	22	22	28
DILATION	RESTRICTOR FITTED TO LIMIT DILATION TO 30%-35%					
CORD PREP. TYPE	(2) 104 ends	(2) 104 ends	(1) 98.5 ends	(2) 80 ends	(2) 64 ends	(3) 49.25 ends
STAGGERED JOINTS COVER/LINER	YES	NO	NO	YES	NO	NO
CURE TIME (307°F)	40 min	45 min	60 min	60 min	45 min	45 min
INTERLAYER BETWEEN CORD LAYER & LINER	YES	YES	YES	YES	YES	YES
HIGH CONSOLIDATING PRESSURE - CORD PREPS.	NO	YES	N/A	NO	YES	N/A
AIRBAG PRESSURE DURING CURE	160 psi	400 psi	160 psi	160 psi	400 psi	400 psi
RIG - A : END LOAD B : CONSTANT LOAD	A	B	A	A	B	A

NOTES: (1) 98.5 ends/100 mm - Standard Tyre Preps.
(2) Prep. made by Textile Dept. at Research Centre
(3) Made by removing alternate cords from Standard Tyre Prep.

TEST CONDITIONS: Free length of hose (between end fixings) 155 mm ± 5 mm
Rotation of free end 90° ± 10°
Frequency of Cycling 12-18 cycles/minute
Compressed air supply pressure 80 psi ± 5 psi
All hoses built with 52½° cord angle
50 mm cord diameter



GRAPH SHOWING EFFECT OF CORD SPACING ON FATIGUE LIFE OF TORQUE HOSES.

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