Condition Monitoring Methods and Economics

A paper presented by M.J. Neale and B.J. Woodley at the Symposium of the Society of Environmental Engineers held at Imperial College, London, September, 1975.

It is based on the much fuller report prepared for the Department of Industry in 1975, which has now been revised to include the latest 1978 data and is to be published by HMSO during 1978 for public purchase.

16–054

Brüel & Kjær

Condition Monitoring Methods and Economics

M.J. Neale B.J. Woodley

Principles and methods

As a starting point for any discussion on condition monitoring it is useful to define what is meant by the term, and to describe how it relates to other techniques used in the operation and maintenance of machines, such as alarm and shut down systems or methods for failure and problem investigation.

The crudest method for operating machines is to run them until they fail, and then to try and repair them in order to make them fit for further service. This method of operation can be very expensive in terms of lost output and machine destruction, and in addition can involve hazards to personnel. It is now well recognised that, particularly in the case of large and expensive plant, it is more economical and operationally satisfactory to carry out regular maintenance. This involves the maintenance of the machine or its various components at regular intervals, to reduce the likelihood of failure during a time when the machine is required to be available for use. The problem in planning this type of maintenance lies in the choice of an appropriate maintenance interval for the machine, because the actual running time before maintenance is really needed is not constant, but varies from one occasion to another, due to differences in the operation of the machine in the behaviour of its components. Fig.1 shows how the running time to failure of a typical machine would be likely to vary if no preventive maintenance were carried out. The vertical line in this diagram represents the safe time interval between preventive maintenance work which could catch all the failures before they occurred. If this safe overhaul interval is chosen, however, there will be many occasions when the machinery will be overhauled long before it is really necessary, such as in those cases at the right hand side of the curve where it could have run on for much longer without failing. This situation wastes production time, and by increasing the frequency of maintenance operations increases the incidence of human errors on reassembly of the machine.

A more satisfactory compromise in terms of maintenance strategy is to carry out preventive maintenance at what may be irregular intervals, but to determine these intervals by the actual condition of the machine at the time. For such condition-based maintenance to be possible, it is essential to have knowledge of the machine condition and its rate of change with time. The main function of condition monitoring is to provide this knowledge.

There are two main methods used for condition monitoring, and these are trend monitoring and condition checking. Trend monitoring is the continuous or regular measurement and interpretation of data, collected during machine operation, to indicate variations in the condition of the machine or its components, in the interests of safe and economical operation. This involves the selection of some suitable and measurable indication of machine or component deterioration, such as one of those listed in Fig.2, and the study of the trend in this measurement with running time to indicate when deterioration is exceeding a critical rate. The principle involved is illustrated in Fig.3, which shows the way in which such trend monitoring can give a lead time before the deterioration reaches a level at which the machine would have to be shut down. This lead time is one of the main advantages of using trend monitoring rather than simple alarms or automatic shut down devices.

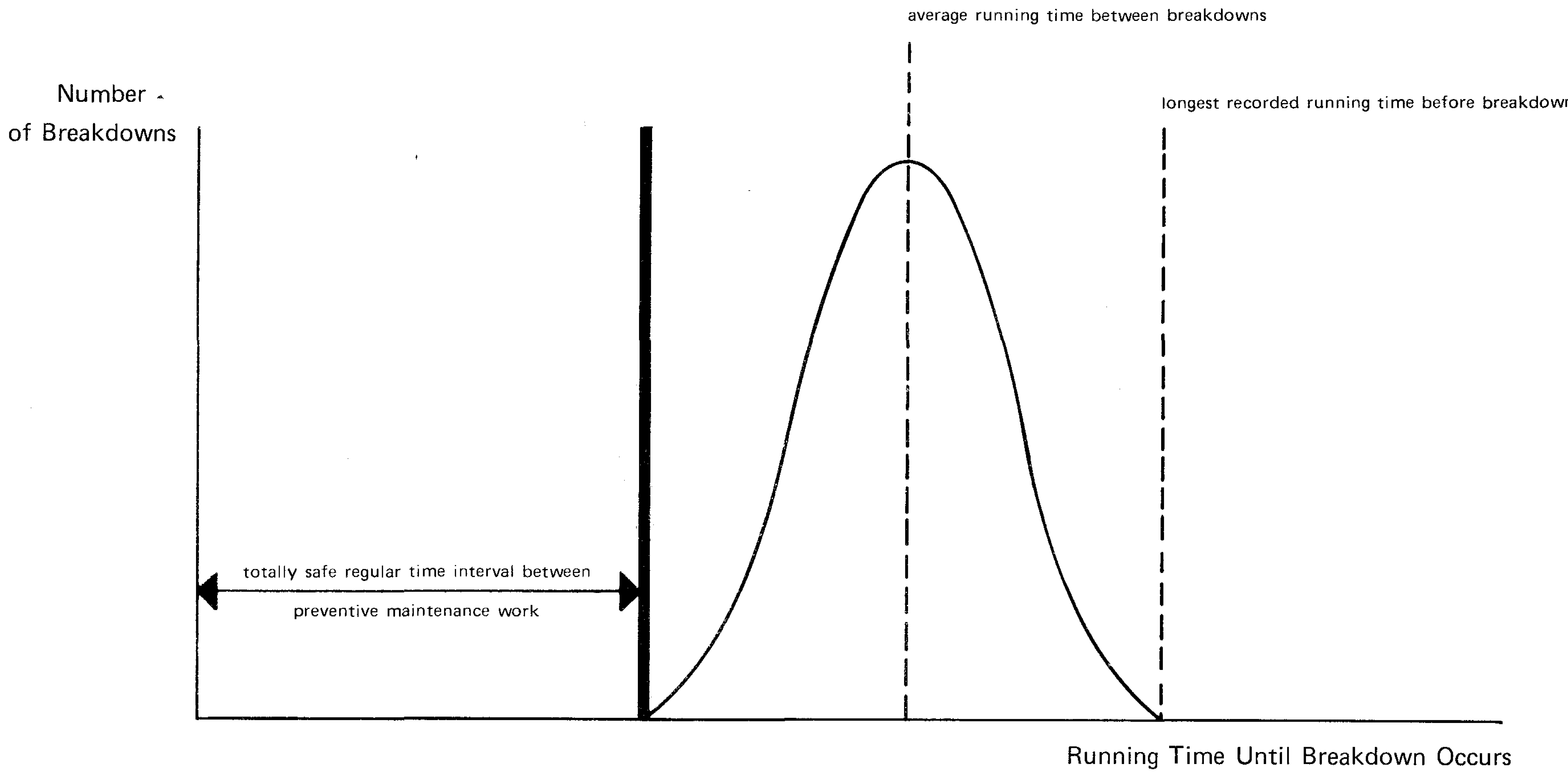

Fig. 1. The typical pattern of machinery failure with no Preventive Maintenance

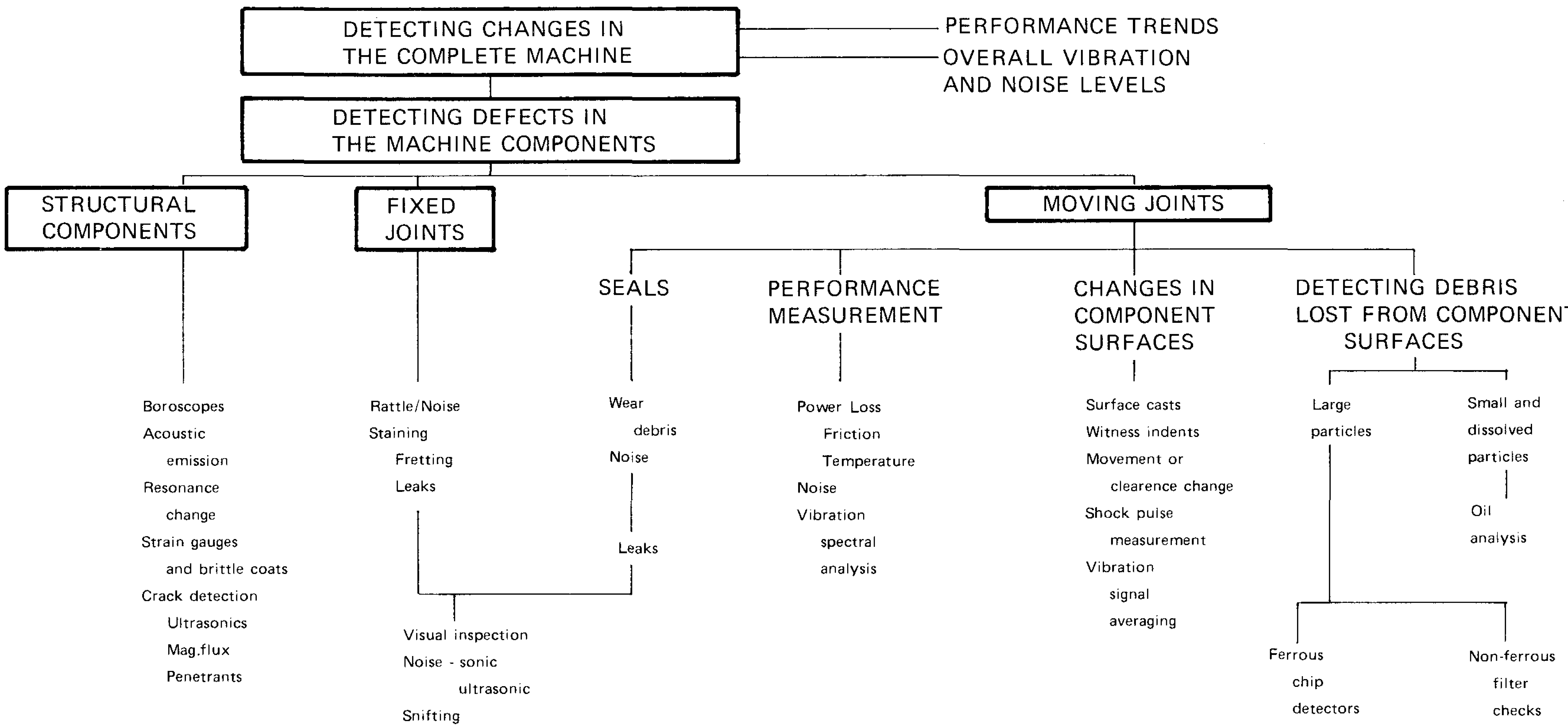

Fig.2. The indications of Machine or Component Deterioration

Condition checking is where a check measurement is taken with the machine running, using some suitable indicator such as, again, one of those listed in Fig.2, and this is then used as a measure o the machine condition at that time. To be effective the measurement must be accurate and quantifiable, and there must be known limiting values which must not be exceeded for more than a certain number of permitted further running hours. To fix these values requires a large amount of recorded past experience for the particular type of machine, and this makes the method less flexible than the trend monitoring, particularly if it is required to give lead time as well as machine knowledge. It can be particularly useful, however, in a situation where there are several similar mahines oerating together as in this case comparative checking can be done between the machine which is monitored, and other machines which are known to be in new or good condition.

These two methods of condition monitoring are compared in greater detail in Table 1, and the resulting advantages in terms of the provision of lead time and better machine knowledge are shown in Table 2.

The economics of condition monitoring

The main savings which can be made by the application of condition monitoring to industrial machinery arise by avoiding losses of output due to the breakdown of machinery, and by reducing the costs of maintenance.

Output related losses can be estimated from the number of days output lost multiplied by the added value output per day. The maintenance costs which can be saved are rather more difficult to quantify, but are likely to relate mainly to the labour costs of breakdown maintenance. Both these forms of saving have been studied in greater detail in a recent survey carried out for the Department of Industry (Refs.), and a figure of the order of £ 750 million per year has been estimated for the maximum conceivable saving which could be obtained by applying condition monitoring across the whole of British Industry. This is shown in Fig.4, which also gives the contributions to this total figure which could be made by the various industrial sectors. This suggests that the savings which might be made, on this basis, amount to an average of about 1% of added Value output with a range for various sectors of from 0,5% to 3%.

Of the total sum of £ 750 million per year, 65% arises from output related savings and 35% from maintenance related savings. Unfortunately this figure of £ 750 million per year is not really obtainable as a real saving, because not all industrial plant, processes and establishments are suitable for the application of condition monitoring.

One method of obtaining a more realistic figure for the likely savings is to identify the industrial sectors which operate suitable plant machinery, and then to take the savings from these sectors only, in order to reach a more realistic total.

Industrial sectors which rely on machinery rather than on manual work to produce their output will be particularly appropriate for condition monitoring, and sectors of this type will have a high value of:

Annual capital invested in plant and machinery per employee.

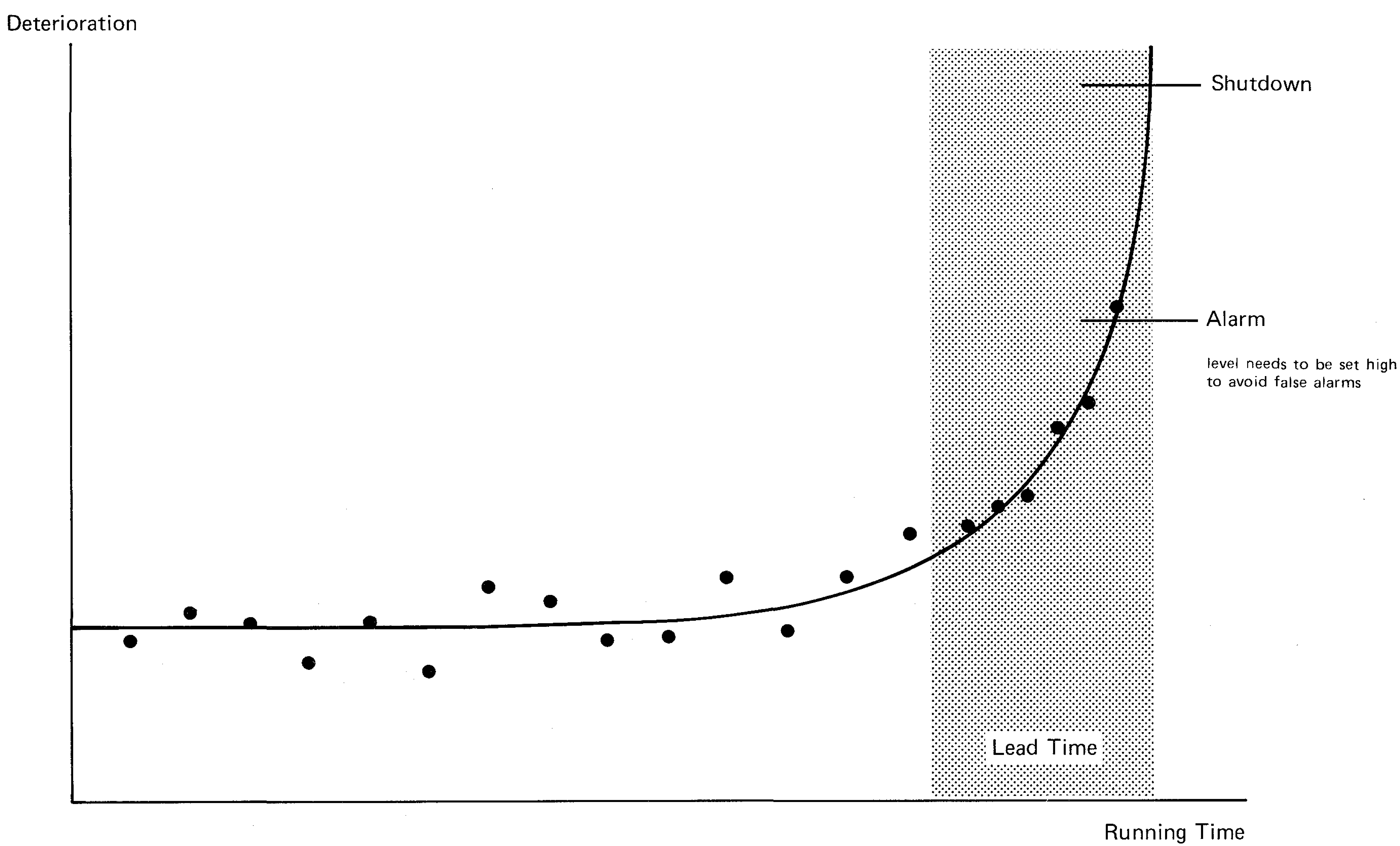

Fig.3. The regular Monitoring of Deterioration to give advanced warning of failure

	TREND MONITORING	CONDITION CHECKING	PROBLEM OR FAILURE DIAGNOSIS
TIMING OF MEASUREMENTS	Readings taken at regular time intervals while the machine is running.	Readings taken at one time while the machine is running.	When the problem has become manifest or after failure has occurred.
QUALITATIVE MEASUREMENTS	Skilled operators can do subjective trend monitoring if they are close enough to their machines.	Typical activity of an engineer when checking a machine during operation.	When machine is stopped, inspection of components can indicate the cause of the problem.
QUANTITATIVE MEASUREMENTS	The taking of regular measurements and their recording and analysis gives a <u>lead time on machine problems.</u>	Numerate values allow comparison with established standards or other similar machines to give <u>knowledge of machine condition.</u>	Measurements may be analysed in considerable detail to provide guidance on possible causes of the problem.
	CONDITION MONITORING		

Table 1. A comparison of Methods of Condition Monitoring and of Failure Diagnosis

<table>
<tr><th rowspan="2"></th><th colspan="2" rowspan="2">ADVANTAGES OBTAINED</th><th colspan="2">METHODS BY WHICH CONDITION MONITORING GIVES THESE ADVANTAGES</th></tr>
<tr><th>Lead Time</th><th>Better Machine Knowledge</th></tr>
<tr><td>SAFETY</td><td colspan="2">Reduced Injuries and Fatal Accidents to Personnel caused by Machinery.</td><td>Enables plant to be stopped safely when instant shut down is not permissible.</td><td>Machine condition, as indicated by an alarm, is adequate if instant shut down is permitted.</td></tr>
<tr><td rowspan="4">OUTPUT</td><td rowspan="2">Increased Machine Availability</td><td>More Running Time</td><td>Enables machine shut down for maintenance to be related to required production or service, and various consequential losses from unexpected shut downs to be avoided.</td><td>Allows time between planned machine overhauls to be maximised and, if necessary, allows a machine to be nursed through to the next planned overhaul.</td></tr>
<tr><td>Less Maintenance Time</td><td>Enables machine to be shut down without destruction or major damage requiring a long repair time.

Enables the maintenance team to be ready, with spare parts, to start work as soon as machine is shut down.</td><td>Reduces inspection time after shut down and speeds up the start of correct remedial action.</td></tr>
<tr><td colspan="2">Increased Rate of Net Output</td><td></td><td>Allows some types of machine to be run at increased load and/or speed.

Can detect reductions in machine efficiency or increased energy consumption.</td></tr>
<tr><td colspan="2">Improved Quality of Product or Service</td><td>Allows advanced planning to reduce the effect of impending breakdowns on the customer for the product or service, and thereby enhances company reputation.</td><td>Can be used to reduce the amount of product or service produced at sub-standard quality levels.</td></tr>
</table>

Table 2. The advantages obtained by the use of Condition Monitoring

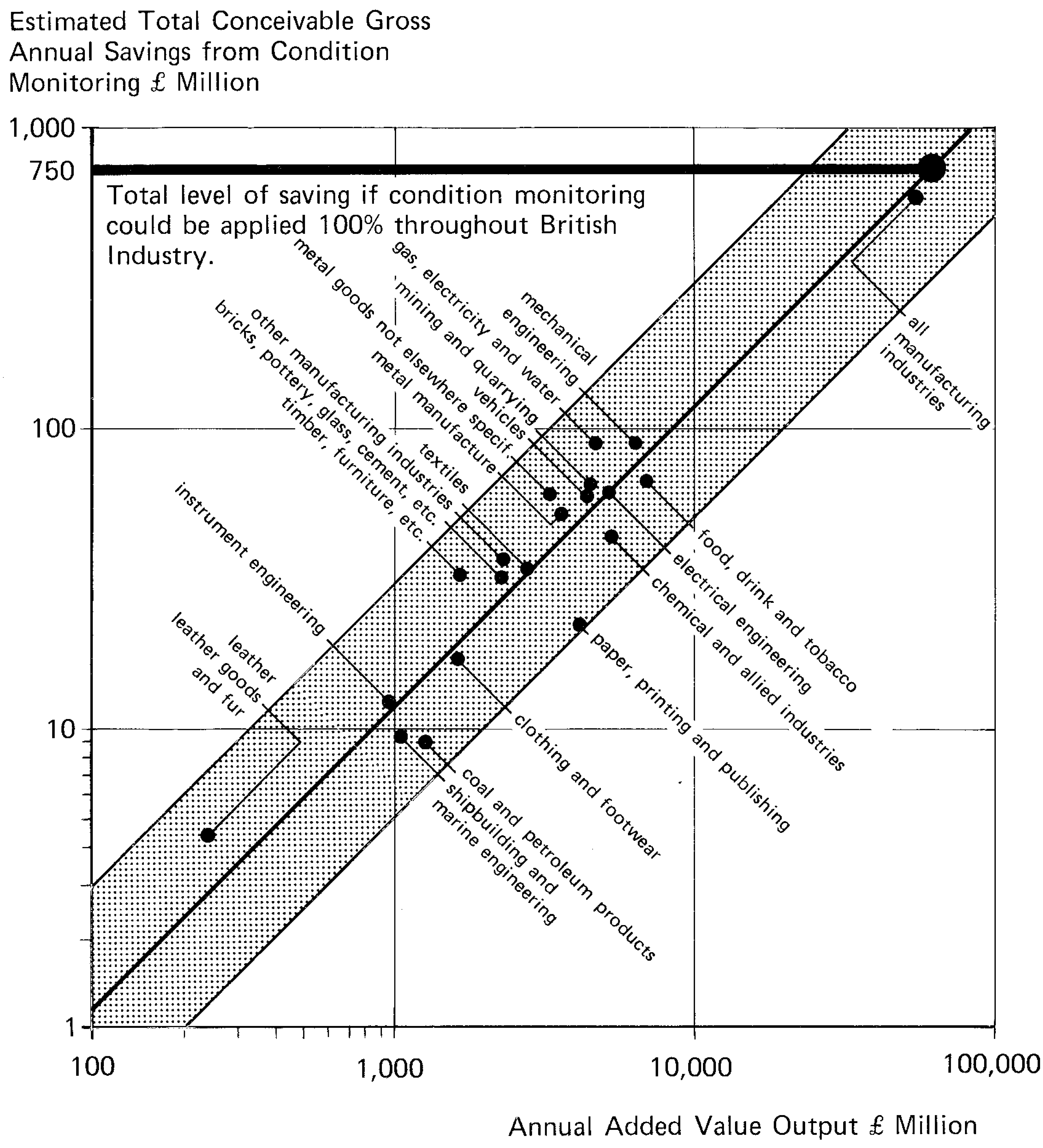

Fig.4. The total conceivable gross annual savings from Condition Monitoring in the United Kingdom (January 1978 values)

Also, if the plant is concentrated in one place and operated intensively, condition monitoring will again be particularly applicable, and industrial sectors using plant in this way will have a high value of:

Annual added value output per establishment.

Thus, guidance can be obtained as to the likelihood of the ownership of machinery which is suitable for condition monitoring in various industries, if these two variables are compared, and Fig.5 shows such a comparison for those industrial sectors which make up the extraction industry, the manufacturing industry, and the utilities of the United Kingdom. On this diagram, the sectors which are towards the top right hand corner will have the highest value of both variables, and will be particularly likely to contain industries using machinery which is suitable for condition monitoring. Industrial sectors towards the bottom left hand corner are likely to have unsuitable machinery.

When only those sectors which are above average in suitability for condition monitoring are selected from Fig.5, a more realistic figure for the estimated savings of the order of £440 million per year is obtained. This, however, is still rather high because some of the establishments in these industrial sectors may be too small to apply condition monitoring effectively. This idea arises from experience with condition monitoring at the present time, which suggests that for successful application it is necessary to have at least one man at an establishment who is involved full time on condition monitoring. In this way he can maintain his expertise at interpreting readings and trends. In the recent survey (Ref.) the critical size of establishment from this point of view was assessed as corresponding to an added value output of £1 million per year. This corresponds in the relevant industrial sectors of British industry to a total of about 2000 establishments, and as a result drops the maximum savings which industry could obtain, using its own staff for monitoring, down to £300 million per year. The lost savings could, however, probably be recovered by the provision of external condition monitoring services supplied under contract to smaller industrial establishments by a specialist organisation.

Finally, any estimate of the likely savings needs to take into account the operating costs of condition monitoring systems and based on a study of similar activities included in the survey (Ref.), a figure for operating costs of about 16% of the gross saving appears to be reasonable. This corresponds to a total national cost of about 16% of the gross saving appears to be reasonable. This corresponds to a total national cost of £50 million, and a total probable net saving of £250 million pounds. This is brought out more clearly in Fig.6, which shows how this net saving is likely to be obtained as a progressively greater number of industries decide to use condition monitoring. This figure also shows that, with some improved techniques and with the wide provision of external services to industry, for the condition monitoring of plant, a further £150 million per year might be saved.

Equipment Requirements

If the application of condition monitoring can be expanded to the degree indicated in Fig.6 with a probable net annual saving to industry of £250 million, there will be considerably increased market for condition monitoring equipment. The studies of the costs of operating condition monitoring systems have suggested that the achievement of net savings of £250 million is likely to correspond to an equipment market of the order of £ 13 million per annum. This figure mainly relates to the supply of equipment for use by larger establishments for carrying out their own monitoring, and the market is likely to take a few years to build up to

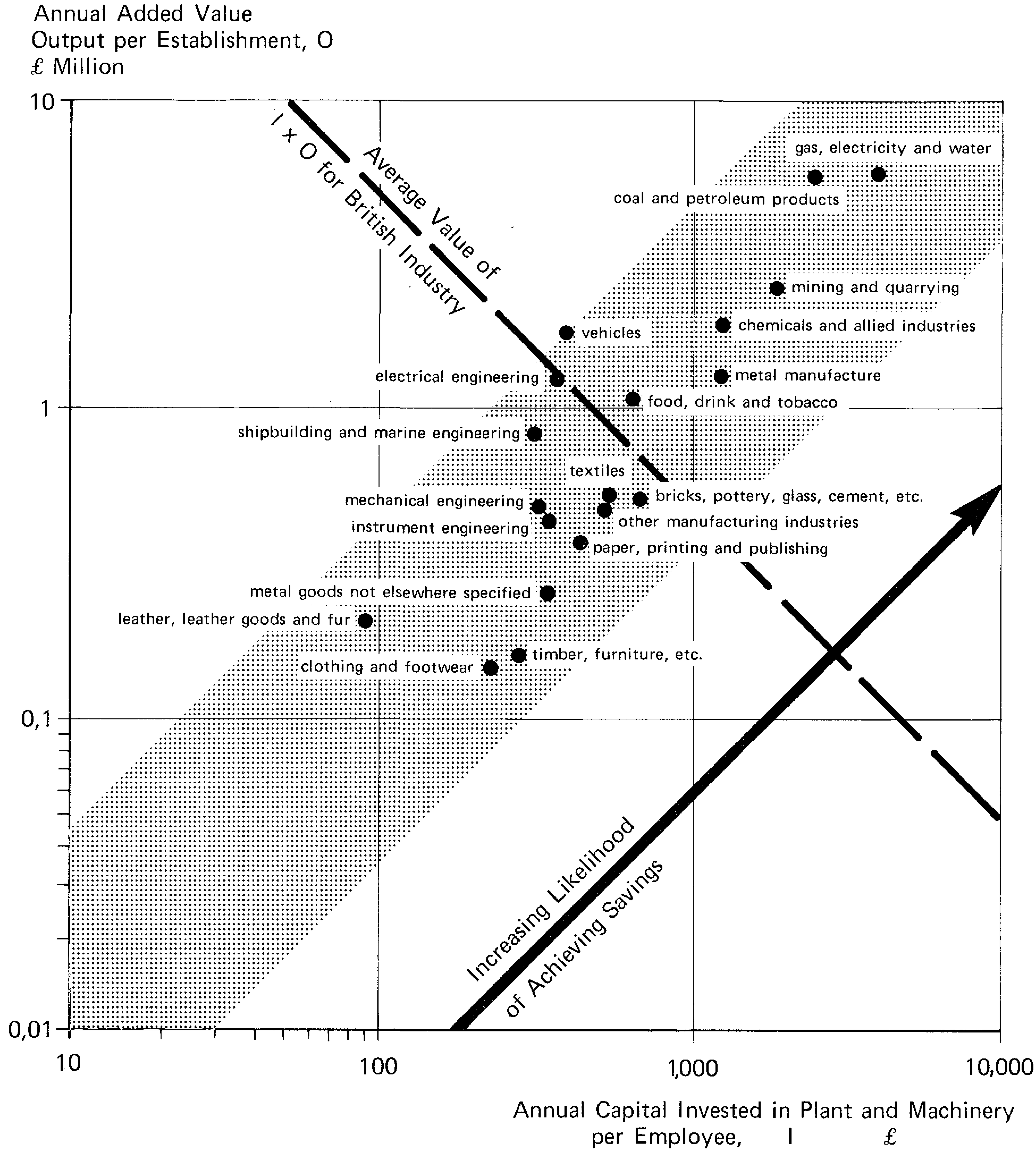

Fig.5. The selection of industrial sectors which are suitable for Condition Monitoring (January 1978 values)

this level. In addition, however, there is the need for equipment for use by organisations providing contract services in condition monitoring for smaller industries, and if these can be stimulated as well, the £ 13 million per annum level of the potential market should be reached more rapidly, and probably exceeded in due course. In the much longer term there could also be a further increase in the size of the market if a new generation of equipment can be developed to help smaller industries to do their own monitoring without the need to use external contract services to as large an extent as might otherwise be necessary.

The existing equipment tends to be unnecessarily elaborate and expensive, and a considerable market exists for simpler and cheaper equipment. The latter could provide a new opportunity within the condition monitoring equipment market, which British instrument and electronic equipment manufacturers might be stimulated into entering.

The equipment needs to have a number of special features, which are not fully met by that which is available at present. The following points which emerged from the survey may be of some help to potential manufacturers:

1. The equipment must be robust to stand inevitable misuse. Equipment designed for laboratory bench top use is not suitable. Indicating instruments must stand being dropped, leads must tolerate being trampled on, and the whole equipment must be resistant to dirt, dust and common industrial fluids. Portable equipment needs to be particularly robust, and should have its own internal battery power supply.

2. The equipment must be reliable and have a simple facility for checking its calibration or correct operation, so that the user confidence can be maintained.

3. The equipment must have sufficient accuracy and consistency to enable it to be used for checking trends when taking measurements over a period of the order of a year.

4. The equipment may often have to be used in hazardous areas, and an intrinsically safe version needs to be available.

5. Electronic equipment and its leads need to be suitably screened, as it frequently has to be used in areas where high interference levels may exist.

6. There are probably three levels of equipment required:

   (a) Very simple portable equipment with a simple unswitched indicator or warning lights, for use by relatively unskilled personnel.

   (b) More comprehensive, but still portable, equipment for use by more skilled or specialist operators doing trend monitoring or condition checking.

   (c) Comprehensive special equipment for the continuous monitoring of particular plants. This can be installed and commissioned by experts, and operated under skilled supervision.

There were also some needs for new equipment and methods, which emerged from the survey, and which could provide guidance for further research and development. Examples of these needs are:

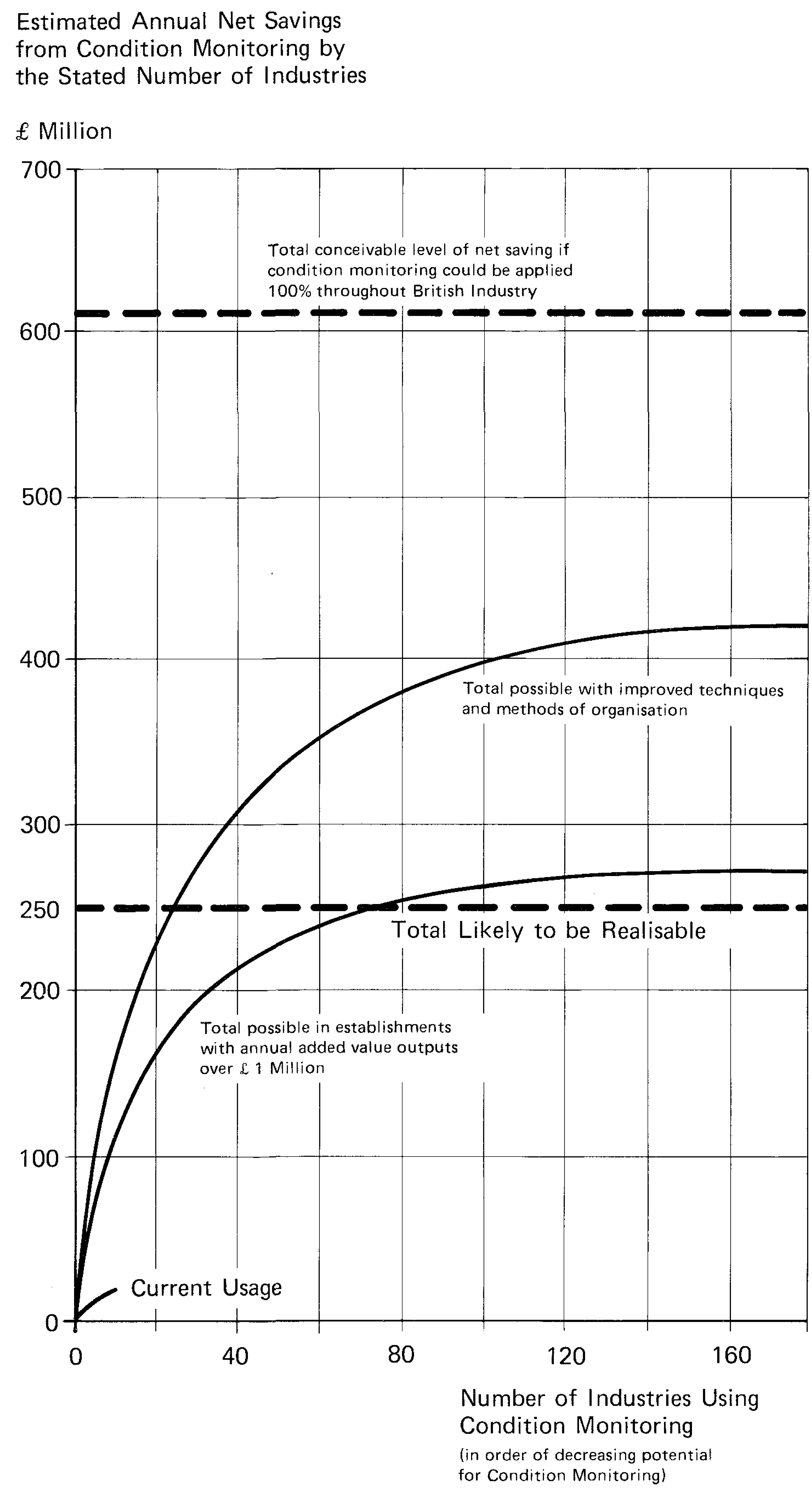

Fig. 6. The broad pattern of annual savings from Condition Monitoring in the United Kingdom (January 1978 values)

1. One of the main limitations on the wider application of condition monitoring is the cost of the labour required to study trends in the information being monitored. Instruments which are trend sensitive rather than instantaneous value sensitive could have a wide application.

2. There is a need for better practical equipment for the condition checking of smaller machines containing many high speed small components, and for determining which component is defective. A simplified form of vibration monitoring with signal averaging is probably one such technique.

3. There is a need to develop an improved method of monitoring hydraulic systems.

4. There is a lack of industrial flow measuring techniques which can conveniently be installed in an existing machine.

Concluding comments

This paper is based on the much fuller report of the Survey of Condition Monitoring for the Department of Industry (Ref.), and it is hoped that the data extracted from it will indicate the technical and economic importance of condition monitoring, and will give plant users and equipment manufacturers an indication of the interest that they should be taking in the subject.

References

1. A Survey of Condition Monitoring in British Industry and its Potential for wider Application. Michael Neale and Associates Report TRD 187 for the Department of Industry. June 1975.

2. An Updating of Report TRD 187 (1975) to Determine the Potential in 1978 for the Application of Condition Monitoring in British Industry. Michael Neale and Associates Report TRD 223 for the Department of Industry. April 1978.