THE SPRING RESEARCH AND MANUFACTURERS' ASSOCIATION

THE APPLICATION OF STATISTICAL PROCESS CONTROL METHODS TO WIRE MANUFACTURE

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SUMMARY

This survey has been undertaken to identify the current quality control practices employed by wire manufacturers and to establish those quality features of spring wire which are of importance to the ultimate quality of springs. The various process parameters which affect wire quality have been examined and the problems associated with the effective application of Statistical Process Control (S P C) techniques to wire manufacturing operations have been analysed.

At the present time the implementation of S P C by wiredrawers is still in its infancy compared with some other industries. Certain process operations have, however, been identified as areas where S P C could be effectively used with little or no modification to existing manufacturing practice. Extension of these principles to some other process parameters and wire characteristics appears dependent on the availability of suitable sensoring and measuring equipment and further development work will be necessary before S P C can be applied in these cases.

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1. INTRODUCTION

In order for springmakers to manufacture products which satisfy the customer's expectations with respect to reliability and performance the manufacturer, in turn, needs assurance that the quality and consistency of the raw material from which springs are made is to an acceptable standard. The important features of a "good" spring wire are its predictable behaviour in the various manufacturing operations to which it is subjected during spring making, and the possession of adequate mechanical properties which will withstand the operating conditions imposed in service.

Just as the springmaker has a responsibility to his customer to supply springs which are fit for their intended purpose, so the wire manufacturer has a similar responsibility to the springmaker. To achieve this objective is not just a matter of undertaking in-process and final inspection of the product itself (quality control) but involves all activities and functions concerned with the attainment of quality (quality assurance). Quality Assurance is therefore a much wider concept applied to all aspects of the manufacturing operation and concerns measurement, control and where necessary, improvement in quality.

The last decade or so has seen the gradual introduction of Statistical Process Control (S P C) techniques to British industry, designed to monitor the quality of manufactured products and as a means of improving process efficiency and the quality of the product. The concepts of S P C are not new; having first been published in 1933 these techniques saw only spasmodic and limited application by industry over the next 20 years. Not until the mid 1970's did the application of these techniques take on any significance in the western world, largely at the instigation of the Ford Motor Company.

Following Ford's example, other motor manufacturers have adopted similar S P C techniques for controlling quality, leading in turn to an extension to many other sectors of industry, notably electrical/electronics, domestic white goods, chemical and pharmaceutical industries. Proponents of the application of S P C would argue the desirability of all producers involved in the manufacturing chain employing similar techniques based on statistical theory.

Pressure is now being brought to bear by some large and powerful industrial customers, for springmakers not only to apply these methods themselves but to require their own sub-contractors and raw materials suppliers to institute S P C in order to guarantee quality and reliability.

Although the application of S P C is not a mandatory requirement of BS 5750: Part 2: 1987 or Defence Standard 05-24, besides the supplier's responsibility for the quality of the raw material he supplies, the springmaker has an equal responsibility for the quality of material he purchases. This requirement of modern quality assurance standards has led to greater emphasis being placed on sub-contractor, material supplier, assessment (vendor appraisal) in some form or another, in recent times.

When properly applied, S P C is a powerful technique for maintaining product quality and forms the basis for continuous quality improvement. To date these techniques have largely been applied to finished products and component items but this is widening to encompass more primary process operations such as raw material manufacture. This survey has therefore been carried out to determine the extent to which statistical process control principles are being used by wire manufacturers and to establish those areas where S P C methods might be fruitfully employed in the future.

2. CURRENT QUALITY CONTROL PRACTICE

Clearly the extent of quality control employment by wire manufacturers varies from company to company and it would be inappropriate to identify or to detail individual company Q C procedures other than in the broadest terms. All companies surveyed during this project had Q C systems to ensure the finished wire product met the requirements specified in national or house standards.

In wire manufacture, the Q C activities can be divided into two distinctly different areas, namely, the monitoring of the properties and characteristics of the material being processed and the control of the various processing parameters which influence the properties and characteristics of the wire being produced. Companies undertake inspection at three separate stages; in-coming, in-process and final inspection. Each of these activities is designed to monitor and control pertinent characteristics of the material which have an influence on the ultimate quality of the finished wire. The purpose of each of these stages is analysed briefly below.

2.1 In-coming Materials Inspection

The production of high quality spring wire commences with an examination and evaluation of in-coming hot rolled rod. This is designed to ensure the suitability of the rods for further processing to meet the specified requirements of the finished wire. The properties, characteristics and the chemistry of the rods have a considerable influence on the drafting schedule to adopt to achieve the required tensile strength, and also affect other quality features of the wire.

It is therefore necessary for the wire manufacturer to possess this information, provided either by the rod manufacturer or from direct measurement at the in-coming inspection stage. Besides analysis and tensile strength, in-coming inspection usually covers such aspects as metallographic features of the rod (structure, grain size, inclusion size and distribution, decarburisation), surface condition and the presence of surface defects as well as the physical measurement of diameter and diameter variation.

2.2 In-Process Inspection

Production of high strength wire from controlled cooled rods involves three essential production steps, rod cleaning, coating and drawing - or four if there is a need to undertake a patenting heat treatment. The production of fine diameter wires could require a further sequence of operations involving patenting, wire cleaning, coating before final drawing to finished size. Wherever it is practicable, however, the number of essential production steps is kept to a minimum by careful choice of material composition, tensile strength and rod size, thereby contributing to an economical production route.

After each of the production steps identified above there is an opportunity for the wire manufacturer to conduct some form of in-process inspection on the material being processed. In the case of rod or wire cleaning and coating this may involve only a simple visual inspection of the material to judge the efficiency of the process. On the other hand, where inter-stage patenting has been carried out, it is customary to check the resulting tensile strength and perhaps the level of decarburisation and the ductility of the wire before proceeding to the next stage in the manufacturing sequence.

From a practical standpoint there is no convenient means of measuring the tensile strength of wire once it is being processed through a continuous multi-hole wire drawing machine. The only opportunity for sampling a coil of wire, for the purpose of mechanical testing is, therefore, after drawing through the last die. Typically, five to ten dies may be used to effect the necessary reduction in section size and increase in tensile strength to satisfy a spring wire specification. In order to meet the specified tensile strength at the finished size the wire manufacturer must take into account such factors as analysis (particularly the carbon content and, to a lesser extent, the manganese content), the tensile strength at the commencement of drawing, the work hardening rate of the material, the drafting schedule (ie the reduction of area per die and the number of dies used), and the drawing speed (as it affects heat generated during drawing). A data bank of information is therefore required, accumulated from past experience and pilot trials, to enable him to determine a suitable production schedule. Having established the precise method of manufacture it is imperative that all the process variables remain under control if a consistent and satisfactory wire is to be produced.

Typical processes which require monitoring and controlling during the production of wire from hot rolled rod include acid cleaning, coating (eg lime/phosphate/borax) and patenting, and may involve one or more variables such as temperature, bath concentration, atmosphere and process time as appropriate.

The control of temperature is a relatively simple matter and is normally achieved by means of automatic temperature control equipment and, provided the instrumentation is properly maintained, should not be a source of product variation. In many cases permanent strip chart records are employed and suitably annotated against the particular batch being processed.

The control of acid content in cleaning baths and chemical concentrations in coating baths is generally accomplished by routine sampling and simple testing or analysis by laboratory, quality control or supervisory staff. The frequency of sampling is determined from past experience and is related to the speed with which the acid or chemical substance is consumed by the process. Depending on the results of the test or analysis most manufacturers operate procedures which prescribe the additions to be made to the baths to maintain acid/chemical concentrations at an acceptable level.

In order to preserve the surface integrity of wire during patenting or continuous hardening and tempering, heat treatment is carried out under a suitable protective atmosphere produced either by fully automatic gas generators or by controlled combustion to provide a neutral atmosphere, thereby avoiding decarburisation and heavy scaling. The frequency of monitoring gas atmospheres varies considerably from plant to plant. Clearly at the start-up of the process gas sampling is undertaken very frequently until the required conditions are obtained, after which the heat treatment atmosphere may only be checked on a weekly basis.

Process times are very much dependent on the production installation. For instance, with modern in-line processing involving patenting, cleaning and wire coating, the through-put speed is critical and is determined by the physical size of the respective processing units, the temperatures employed and the size of the material being processed. Once the optimum process times have been established these should remain constant unless there is strong evidence from inspection and testing to support a change.

Batch processing involving the aforementioned production steps is more flexible with respect to process times; it is, however, in general more costly for bulk production due to the increased handling. Although prescribed process times operate in most plants, batch processing will readily allow modifications to be made should the need arise without affecting any subsequent production operation.

2.3 Final Inspection

To meet the requirements specified in British Standards covering spring steel wires, all manufacturers are obliged to undertake final inspection on finished wire prior to despatch.

All standards specify tensile strength along with one or more tests to determine the wire's ductility. The physical dimensions of the wire, such as diameter and ovality, are closely controlled and are required to meet prescribed tolerances. The all important surface condition of these materials (ie defects and decarburisation) is determined by recourse to deep etching and visual examination, metallographic examination and by prior arrangement, non-destructive inspection techniques.

The standards specify the level of inspection to be performed and in the vast majority of cases call for final inspection to be carried out on samples taken from each end of every coil constituting a batch. Where wire is supplied on spools/reels/formers, due to the practical difficulties of sampling the inside end of the coil, the level of inspection is relaxed to sampling the leading end only.

It is customary for wire manufacturers to supply springmakers with the results of final inspection tests in the form of a materials test certificate.

3. SPRING WIRE CHARACTERISTICS

The characteristics of wire which influence their suitability for use as light spring materials can be summarised under the broad headings of mechanical properties and metallurgical features and can be used to describe the quality of spring wires.

3.1 Mechanical Properties

Since the function of a spring is to act as an elastic element, the first requirement is for material possessing a high elastic limit. Unfortunately the elastic properties of wire are not easily determined on a routine basis and so the tensile strength is measured and taken as an indication of the elastic properties of the wire. Relationships have been established between tensile strength and the elastic limit in tension and in torsion, and these are used widely for the purpose of design.

Many springs operate under dynamic stress conditions and therefore materials need to exhibit good resistance to fatigue. The resistance of a material to alternating stress is influenced by the mechanical strength as well as other metallurgical features which will be considered later. It is well known that, up to some optimum value, the fatigue resistance of wire is directly proportional to its tensile strength; therefore high strength materials are desirable in such situations.

Tensile strength, or more precisely the elastic limit, also has a considerable influence on the ability of springs to resist creep and relaxation in service. Again the higher the tensile strength, the more resistant is the material to plastic deformation with time.

All spring wires must possess sufficient ductility to allow the necessary forming of the spring to the required shape. Hence, there is a need to describe the quality of a spring wire in terms of its ductility as measured by one or more of the following tests, viz, torsion test, bend test, wrap test, reduction of area and percentage elongation.

3.2 Metallurgical Features

The desirable properties of spring wire, and hence the quality, cannot be fully described by sole reference to mechanical properties. Consideration must also be given to the metallurgical features of the wire which include the metallographic structure, inclusion content, extent of surface decarburisation and the level of surface defects.

The majority of spring wires possess patented structures consisting of very fine pearlite. This structure has moderately high intrinsic strength and is capable of further strengthening by cold drawing. The control of inter-lamellar spacing of the carbide and the amount of pro-eutectoid ferrite is necessary in order to obtain optimum properties with respect to tensile strength and ductility.

A smaller proportion of spring wire is produced having a tempered martensite structure obtained by continuously hardening and tempering after wire drawing. Such wires are used for high duty springs where the grain size, fineness of structure and the absence of intermediate transformation products are important features of quality.

The type, amount, size and distribution of non-metallic inclusions play an important part in defining the quality of spring wires. Unacceptable levels of non-metallic inclusions can lead to premature failure under fatigue conditions and in certain cases static failure in service as well as breakage of wire during fabrication. British national spring wire standards rarely specify the acceptable level of inclusions other than in general terms, although some standards contain provision for defined levels of inclusions to be agreed between the manufacturer and purchaser prior to placement of the order. On the other hand 'house' specifications, particularly those used by aircraft industry and for other applications of a safety critical nature, specify in precise terms the maximum level and type of inclusions which can be tolerated.

Although small amounts of suface decarburisation may not adversely affect the performance of a statically loaded spring, the presence of decarburisation on wire used for dynamically loaded springs can cause a serious reduction in fatigue life. Every attempt is therefore made to minimise decarburisation during the hot rolling of rod as well as during wire production.

The surface quality of wire, exemplified by surface cracks, laps, seams, scabs, shells and pits can adversely affect the performance of springs since all these defects are potential stress raisers. The damaging effects on performance will depend on the type and severity of the defect and also on the service conditions to which the spring is subjected. Relatively small defects can have a profound effect on the fatigue strength of springs whereas much larger defects are necessary to affect static performance adversely .

4. EFFECTS OF WIRE PROCESSING PARAMETERS

A pre-requisite for the production of high quality spring wires is the availability of high quality rods having closely controlled composition with a minimum of segregation, regular cross section, suitable metallographic structure and freedom from surface defects, roughness and decarburisation. Some improvement in quality may be possible by the efforts of the wire manufacturer during wire production, but he is limited in what he can do bearing in mind the nature of the processes available and the economic restraints placed upon him. Wire drawers are ever mindful of the need for high quality rods and pay particular attention to assessing rod quality prior to wire drawing, as this has a considerable influence on the manufacturing schedule employed to achieve the required properties in the finished wire.

Accepting the fact that rod quality has a marked effect on final wire quality, the various stages to which the material is subjected during wire-drawing (over which the wire producer has some control) and their contribution to the overall quality of spring wire should be considered.

The desirable features of spring wire have been itemised in section 3 of this paper and the principal process parameters which affect these spring wire characteristics will be examined in an attempt to identify those areas where perhaps the application of more sophisticated quality control techniques may be of benefit.

Clearly the chemical composition, inclusion content, size and distribution are governed by steelmaking and ingot or continuously cast billet practice, which are outside the control of the wire manufacturer. Both parameters need to be closely controlled since chemical composition affects tensile strength, and inclusions the fatigue resistance.

The attainment of the required tensile and the consistency of tensile strength from coil to coil within a production batch are influenced by the production techniques of both the rod roller and the wiredrawer, and are dependent on a number of factors. Where wire is drawn directly to finished size from controlled cooled rods, the rod roller has a responsibility to ensure the tensile strength is controlled to some predetermined level, thereby minimising any necessary changes in wire production scheduling to accommodate varying tensile strengths of the rods. As mentioned elsewhere, the resulting tensile strength produced by controlled cooling or by the patenting operation is very dependent on the carbon content and to a lesser extent on the other elements present in the steel, the rod size and the cooling rate employed.

Besides the initial strength of the rods, the wiredrawer must take into account the inherent work hardening rate of the material, which is particularly affected by the level of carbon; higher carbon contents having higher rates of work hardening. The drafting schedule too has some effect on the final tensile strength, with heavier reductions in cross sectional area per die contributing to a small but significant increase in the work hardening rate.

The speed of drawing has comparatively little effect on the rate of work hardening although it can have a secondary effect due to the temperature generated by the process of plastic deformation of the wire. Bulk wire temperatures in excess of 200°C can be encountered, causing the wire to age harden with a consequent increase in tensile strength and a more marked increase in elastic properties over and above that produced as a result of cold working. Unfortunately this increase in tensile strength as a result of ageing is also accompanied by a serious loss in ductility as measured by the torsion and bend tests. There is a need, therefore, for the wire drawer to control drawing temperatures if unacceptable low ductility wire is to be avoided.

In addition to the effects of ageing, ductility can be affected by the fineness of the pearlitic structure and grain size. Whether patenting is undertaken by the rod roller or wire drawer, control of the process is essential if a satisfactory rod/wire is to be produced.

Rod section characteristics such as incorrect size and ovality can cause problems during the drawing process due to the very high loads imposed on the initial die trying to accommodate these size variations. Damage to the first die and breakdown of the lubricant can cause a knock-on effect to the other dies resulting in wire surfaces which are rough and scraped and completely unsuitable for springmaking. Variations in cross section can also give rise to variations in the tensile strength due to the variable amount of cold reduction the material receives and can lead to situations where the tensile strength falls outside the specified limits, particularly when working to tight tolerance ranges.

The responsibility for irregular section size and shape is largely with the rod roller but, due to the fact that wire drawing dies tend to wear to an oval shape, the wire manufacturer must also maintain control over this feature as uniformity of shape can influence spring coiling and the ultimate properties derived from the spring.

The quality of spring wires, as measured by the absence of decarburisation and surface defects is governed by each of the production stages to which the material is subjected, starting with steelmaking through to wire drawing. Defects in the finished wire can arise at any stage and probably over two-thirds of all defects can be attributed to shortcomings in steelmaking practice, primary rolling if applicable and rod rolling. The wire manufacturer is therefore very dependent on others involved in the production cycle to ensure the levels of decarburisation and defects are controlled to some specified maximum. For his part, the wiredrawer must employ practices which at the very least maintain the material's integrity and in selected cases possibly improve it. The introduction of gross surface defects such as laps, seams, scabs etc by the wiredrawer is most unlikely but on the other hand additional decarburisation, scraped wire, surface roughness and in extreme cases cracking due to overdrawing are possible and are the wiredrawer's responsibility.

5. APPLICATION OF S P C TECHNIQUES

Although the implementation of Statistical Process Control (S P C) could possibly apply with beneficial effect to steelmaking, primary rolling and rod rolling, the purpose of this survey has, of necessity, been directed at the producers of wire since they are the immediate sub-contractor to the springmaker.

It is clear from an examination of the processes involved in wire production that the generally accepted concept of quality control by the measurement of the characteristics of the product by sampling discrete items is not readily applied to wire.

Sampling of finished wire coils for the purpose of mechanical testing is undertaken by all the wire manufacturers interviewed and can provide a valuable source of data with respect to the variability of mechanical properties over a long period of time. With large order quantities, these data can be presented in the form of statistical information giving mean values for tensile strength, diameter and similar characteristics along with an indication of the variability of the property by reference to the standard deviation. However, such data are obtained after all the processes have been carried out and, although useful for judging long term performance and the overall efficiency of the wire drawing processes, cannot be used for the immediate control of tensile strength or other mechanical properties.

The most fruitful avenue of S P C application would appear to be in controlling process variables which themselves, either directly or indirectly, affect the mechanical properties or other quality characteristics of the finished wire.

In-coming rod inspection would appear a possible area where simple statistical methods such as histograms might be applied to give a visual impression of the variation in carbon content and as-received tensile strength. Carbon contents of spring wire could span quite a wide range from about 0.4% up to 0.85% and above for some music wires and, in order to make the diagrams useful, the materials would need to be grouped to 5 points of carbon and confined to a constant rod size. The development of histograms over a period of time would give the wiredrawer a simple means of monitoring rod quality for this important characteristic and also provide an on-going indicator of the variability of supplies. It may then be possible to develop this data collection and display the information as $\bar{X}$ and R charts where appropriate decision rules could be applied concerning acceptability.

Heat treatment processes such as patenting and continuous hardening and tempering undertaken by wire manufacturers are always controlled by automatic temperature instrumentation. Statistical Process Control in the form of $\bar{X}$ and R charts has been sucessfully applied to continuous heat treatment processes in other industries (particularly the motor industry) where discrete items are being processed.

Accepting the problems of sampling wire immediately after heat treatment, the implementation of S P C by wiredrawers should be possible. The argument used by some opponents of Statistical Process Control that the use of automatic control equipment is sufficient to monitor a process and maintain the required quality level may be shortsighted, particularly where the items being treated possess features such as slight changes in composition, grain size and initial structure, which can lead to variability in the property being controlled; in this instance hardness or tensile strength. The acquisition of tensile data will obviously involve a time delay due to sampling and testing before the results can be evaluated and used for the prupose of altering any process parameter, but the attraction of employing $\bar{X}$ and R charts would appear to be in the longer term in that a drift away from the target tensile strength, due perhaps to a gradual deterioration in control instrument reliability or change in composition, would be readily identified and thereby trigger some appropriate remedial action before an unacceptable tensile strength is produced.

De-scaling of rod and wire by acid cleaning processes and the coating of rod and wire for the purpose of assisting lubrication during drawing are operations where the use of S P C techniques would appear particularly relevant. Any process, be it batch or continuous, where both concentrations and temperatures have a significant effect on the material quality could well benefit from such an approach. To ensure a consistent level of quality over extended periods of time it is essential to maintain the process conditions at some optimum level.

The procedures used at the present time vary enormously from plant to plant. In general the operating conditions of batch type processes would appear to be more variable than those for continuous processes where either automatic top-up of solution concentrations are made or more attention is paid to systematic manual adjustment. This area of production seems the most attractive for the application of S P C using $\bar{X}$ and R charts to control chemical composition of liquor baths by monitoring selected characteristics such as acid content, pH, specific gravity, solids content etc.

Electro-deposition processes, for example galvanising and tinning, would also appear very amenable to S P C by measurement of the metal content of the bath; application to hot-dip metal coating would, at this stage, appear problematical.

As stated earlier in this paper, the consistency of wire diameter and absence of ovality are important quality features as far as the springmaker is concerned. At present these characteristics are checked by the operator during the initial setting up of the drawing machine and periodically as the finished wire leaves the machine. The customary method of inspection by operators is by use of hand-held micrometers and, although one or two companies have non-contact methods (laser micrometers) available in their quality control departments, these are not used on the shop floor for routine inspection. Some non-contact method of measurement would seem desirable, attached to the wiredrawing machine at some suitable position to monitor both size and shape of the wire continuously as it is being drawn. A number of companies have attempted to install laser micrometers but the practical difficulties encountered have been considerable and implementation remains at the development stage. Much work needs to be done before the continuous monitoring of size can be incorporated in a Statistical Process Control programme.

The temperature generated during wiredrawing is important if wires having sufficient ductility are to be produced. With modern high speed drawing benches much attention is paid to this aspect and various methods are used, including water-cooled capstans, air-blast cooling and direct water cooling of the wire. Numerous attempts have been made to measure wire temperatures on multi-hole drawing machines under production conditions but, apart from the occasional trial especially set up for the purpose of research and development, these exercises have met with very limited success to date. Clearly a non-contact method of measuring temperature, such as a radiation pyrometer, is needed but equipment currently on the market has limitations in that the size of the target sensing area employed tends to be too large in comparison with the dimensions of most wires. In addition, the actual size of the equipment, and the difficulties of mounting at a suitable position within the machine, present further problems. However, when a suitable design of instrument becomes available in the future, automatic Statistical Process Control of wire drawing temperatures should be a reality. In the meantime wiredrawers will continue to use less exacting means to control wire temperatures by adhering to pre-set drawing speeds, defined procedures for the operation of cooling devices, visual inspection of the wire for evidence of lubrication breakdown due to excessive temperature, and the loss of wire ductility as measured by torsion and bend tests.

6. EXAMPLES OF S P C IMPLEMENTATION

To illustrate the extent to which statistical methods and data presentation have been applied in the wire industry, some examples are cited below:-

i Presentation of mechanical test results in a statistical form is becoming more common. This provides information on the variability of material properties to be expected within a consignment and is often related to tensile strength, ductility and wire size. Using low cost personal computers with a print-out facility the data can be easily generated and incorporated on test certificates.

ii Application of simple charting methods are being used to monitor carbon content and the as-patented tensile strength of wires. In one case, a wiredrawer has been able to optimise the process temperatures used in patenting and thereby position precisely the mean value of tensile strength to the mid-point of the tolerance range, so reducing the possibility of "out of specification" wires.

iii A number of companies are applying $\bar{X}$ and R charts to coating processes such as continuous phosphate and lime coating baths as well as electro-galvanising installations. It was reported that manufacturers were able to tighten chemical and metal contents and in some cases decrease concentrations with ultimate savings in consumables while at the same time improving uniformity of coating thickness.

iv One company claims that, by using Statistical Process Control techniques it was able to solve problems associated with variability of wire diameter. On investigation, the source of variability was traced to inadequate measuring equipment employed by the die shop. Replacement of the suspect instrument with a more accurate laser micrometer was found to be the remedy.

v One company is convinced that variation of lubricant coating thickness has a significant effect on the consistency of dimensions of springs on coiling. To reduce this variability the company is engaged on the development of a novel method for continuously measuring lubricant film thickness at the drawing die. If successful in the endeavour, this indirect method of measurement will be ideally suited to data logging and the production of $\bar{X}$ and R charts to control this parameter.

vi Although not connected with the production of spring steel wires, an example of the potential of Statistical Process Control has been demonstrated in terms of cost savings. By the correct application of $\bar{X}$ and R charts, a wire manufacturer has been able to reduce variability of coil weights supplied to customers, but at the same time guarantee a minimum weight for each coil and as a result has effected annual savings of about £44,000 for this one product line.

7. CONCLUSIONS

i The application of S P C techniques in the wire industry is, in general, very much in its initial stages and lags behind the spring industry by an estimated five or more years.

ii Opinions as to the usefulness of Statistical Process Control are mixed. Companies who have planned carefully the implementation of these techniques to selected processes are convinced of the practical benefits to be gained from using these procedures. On the other hand, the less receptive wiredrawers appear to lack the basic knowledge of the subject and are reluctant, or possibly unable, to devote the necessary time to its study.

iii From this survey it is clear that the most promising areas for S P C application are the wire cleaning and coating processes.

iv Large scale production runs are more amenable to Statistical Process Control. Its application to small intermittent batch production may be more a question of economics than of technical feasibility.

v At the present time the recording of data and development of control charts is undertaken manually. As more suitable instrumentation becomes available it is anticipated there will be a move to automatic plotting methods which are less labour intensive.

vi There is a need for further engineering and technical development before certain wire characteristics such as diameter, ovality and wire temperature can be continuously monitored and thereby provide the necessary data for control by statistical methods.