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The necessity of modern quality improvement and some experience with its implementation in the manufacture of rolling bearings

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SKF restructured its manufacturing world-wide in response to competition from Japan in the early 1970s. The necessity of a company-wide quality procedure soon became evident. Its implementation later paved the way for both the implementation of statistical process control (SPC) and the acceptance of experimental design throughout the company. Topics discussed in this paper include the structure of SKF quality procedures, difficulties that have been encountered and benefits experienced while implementing SPC throughout the organization. Furthermore, experimental design, which is a natural extension of SPC, is discussed with the emphasis on foreseen benefits from its implementation in an organization. Finally, an example is given of how SKF has been able to vastly improve the performance of a bearing in a certain application by using experimental design. Also the manner in which non-contributory factors can be used to decrease the final product's cost is stressed.

Introduction

SKF, with its headquarters in Gothenburg, Sweden, is the world's largest manufacturer of rolling bearings with about 20% of the world market. It employs 40000 people world-wide and manufactures in 14 countries. Annual sales are of the order of £2000 M (1986).

Until the early 1970s each SKF manufacturing company was primarily responsible for manufacturing products for its domestic market. Then, signals from the market indicated that the Japanese bearing manufacturers were beginning to be able to manufacture good quality bearings at a competitive cost.

To meet the Japanese challenge, SKF implemented a total restructuring of manufacturing. The resulting global forecasting and supply system (GFSS) basically means that each individual bearing type is manufactured at only one location. Thus, each company manufactures fewer bearing types and sizes, but produces greater volumes of each (see table 1). Further, each company now has global responsibility for the delivery of its own products.

The importance of ensuring that a bearing made in Sweden, say, was as good as one made in the U.K. necessitated the introduction of a company-wide quality procedure. The first such procedure was issued in 1978. An updated version was issued in 1986 and is derived from the SKF quality map (see figure 1). This quality procedure consists of three levels.

The first level (*Quality assurance manual*) includes

the SKF quality policy;

a general section covering organization, responsibilities and authorities;

a managerial section which states the required procedures in each segment of the quality map, including the interfaces.

The second level consists of common procedures and instructions based on the requirements stated in the *Quality assurance manual*.

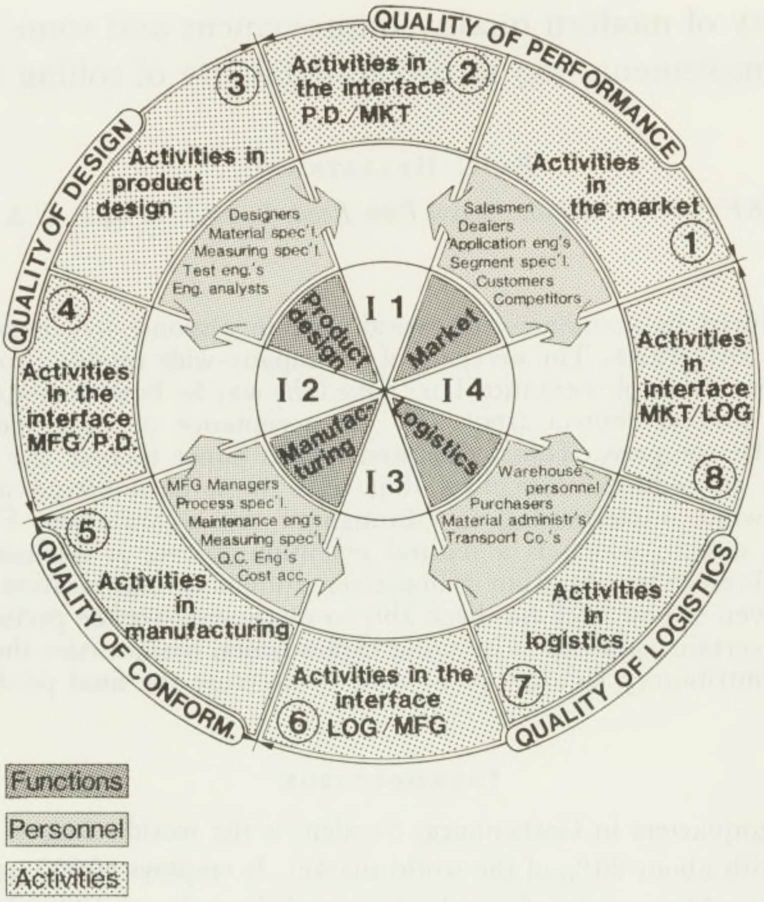

FIGURE 1. The SKF quality map.

TABLE 1. CONCENTRATION OF MANUFACTURE BY COUNTRY AND BEARING TYPE

type	Sweden	U.K.	West Germany	France	Italy	total
			1969			
6203	●	●	●	●	●	5
6204	●	●	●	●	●	5
6205	●	●	●	●	●	5
6206	●	●	●	●	●	5
6207	●	●	●	●	●	5
	5	5	5	5	5	25
			1976			
6203					●	1
6204				●		1
6205	●					1
6206			●			1
6207		●				1
	1	1	1	1	1	5

Several of these procedures and instructions require knowledge of specific techniques. Where necessary these have been issued in separate booklets called *Quality techniques*.

Examples of these are *Process and machine capability studies*, *Statistical process control* (SPC), *Failure mode and effects analysis* and *Gauge capability studies*.

The first and second levels are issued from SKF group headquarters. The third level is issued from the individual companies. Written in the local language, these consist of local company or plant instructions, handbooks, completed forms, etc., each related to actual products and/or processes of the company.

Statistical process control

One of the reasons for issuing the revised 1986 version of the SKF quality procedure was the reintroduction of SPC into the company. We have identified the following basic requirements for a successful introduction of SPC.

Top management commitment is absolutely critical. Implementation of SPC must be given a high priority throughout the entire organization.

Dedicated personnel whose main responsibility is SPC are needed both at staff and factory level. This is especially important during the first 2–3 years when their task is not only to be experts when it comes to technical matters (statistics), but also for practical matters, such as providing the operators with control charts, updating control limits and analysing control charts.

Because of the intimate knowledge of the manufacturing process obtained by these experts, they can readily move on to other equally challenging tasks when SPC is fully implemented in the factory or company.

Proper training is also essential for a successful implementation of SPC. SKF has used a 'top-down' approach, which means that the upper management were the first group to be trained, followed by the middle management. Training for these employees took $1\frac{1}{2}$ days, and consisted of half a day each on basic statistics, capability studies and control charts. Examples and exercises based on data from standard SKF production were used throughout the course.

For the training of the operators, it is important to use data from their own process or machine and to follow up the classroom activities with immediate implementation of SPC. Also, during the first few weeks it is especially important for the operator to receive support from the person responsible for SPC.

Finally, acceptance in the organization is crucial. Attempts to force SPC into a factory or organization will undoubtedly backfire after a while, and to try to introduce SPC 'in a proper way' later will be very difficult.

Although SKF has experienced mostly successful company-wide implementation of SPC, some difficulties have also been encountered. The most difficult group of people to convince of the usefulness of SPC has been middle management. This is because it is their job and authority which will be most affected by the implementation of SPC. One way to counter this might be to provide *them* with the most extensive training and make them the driving force behind implementing SPC in the factory or company.

Some factories have tried to implement SPC without an on-site 'SPC general', without much success because of problems with priorities in the factory. The problems first arose during the implementation phase when there was nobody available to give support to the operators. The initial effort spent in installing SPC was largely wasted. To make matters worse, the next time around when SPC was implemented in a correct manner, there was of course a strong resistance to it from the operators.

Although SPC takes time and a major effort to implement, the many benefits, potential savings and quality improvements that can be made easily justify its implementation. Before SPC was introduced, the operators were given tolerances they had to follow. If their process was not capable it was then common practice to aim the process at the rework side of the tolerances. Different operators then aimed the process at different target values, which resulted in a larger than necessary final product-to-product variation. Control charts are now used, enabling the operators (or different shifts) to aim at a common target value, thus reducing the final product-to-product variation.

Furthermore, use of control charts serves to divide and define the responsibility between the operators and management. It is now the operators' responsibility to keep the process on target, largely by using the $\bar{x}$ part of the control chart. The R part of the control chart is used by the operator to alert the management when the variation of the process, which is the responsibility of the management, is getting excessive. The management then has to take appropriate action.

An additional benefit is that SPC provides a common language through the organization. The operators can show on the control chart what they have complained about for years.

With SPC properly implemented it becomes possible to start work on improving material flow and to reduce the work-in-progress. This in turn leads to a tidier environment. The importance of good housekeeping and cleanliness in producing top-quality products cannot be over emphasized.

SPC is a tool to get the manufacturing process under control, i.e. the outcome of the process becomes predictable. This is a basic requirement for 'just-in-time' production which involves extremely short lead times and basically an absolute minimum amount of work in progress.

Finally, with SPC properly implemented, it is possible to identify and quantify problem areas objectively, enabling priorities for quality improvements and investments to be set.

Experimental design

Experimental design techniques, such as full and fractional factorial designs, blocking and randomization, are a natural extension of SPC. Problems are identified with the help of SPC, while experimental design will help on finding most effective solutions.

Factorial design can be used to solve many types of problems, such as the optimization of a product prototype. SKF had problems some time ago when a standard bearing design did not perform satisfactorily in a certain application. Figure 2 show the design of a bearing. Based on experience, the following design parameters were thought to have an effect on the performance and life of the bearing in this application.

1. Inner ring heat treatment.
2. Outer ring osculation, which is the ratio between the ball diameter and the radius of the outer ring raceway.
3. Cage design.

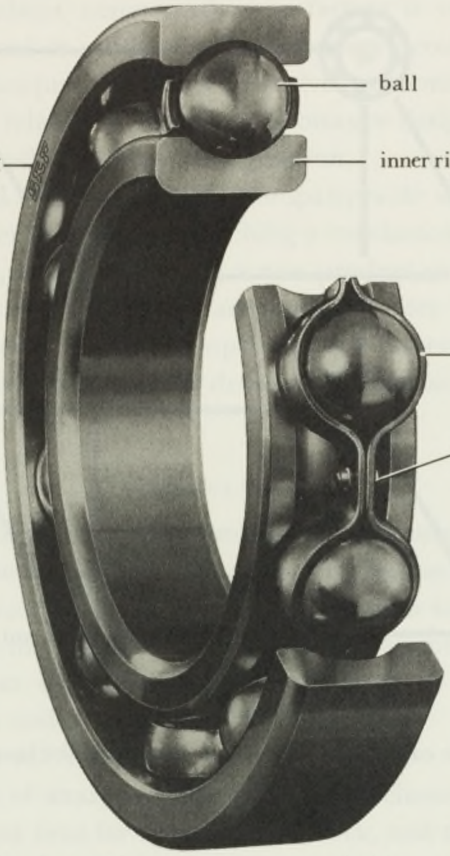

Figure 2. Standard deep groove ball bearing.

It was decided to use a full two-level factorial design to investigate these parameters. The results are displayed in table 2.

Plotting the data (see figure 3), we find that superior performance is achieved with a modified outer ring osculation when using the modified inner ring heat treatment. Thus there is a strong interaction between outer ring osculation and inner ring heat treatment (see figure 4). By using this design modification SKF has been able to supply a bearing in this particular application with a performance far superior to that of the standard bearing previously used. These design modifications result in improved performance only in this particular application.

Table 2

(std: standard design, mod: modified design)

	design parameters			
experiment	1	2	3	life/h
1	std	std	std	17
2	mod	std	std	26
3	std	mod	std	25
4	mod	mod	std	85
5	std	std	mod	19
6	mod	std	mod	16
7	std	mod	mod	21
8	mod	mod	mod	128

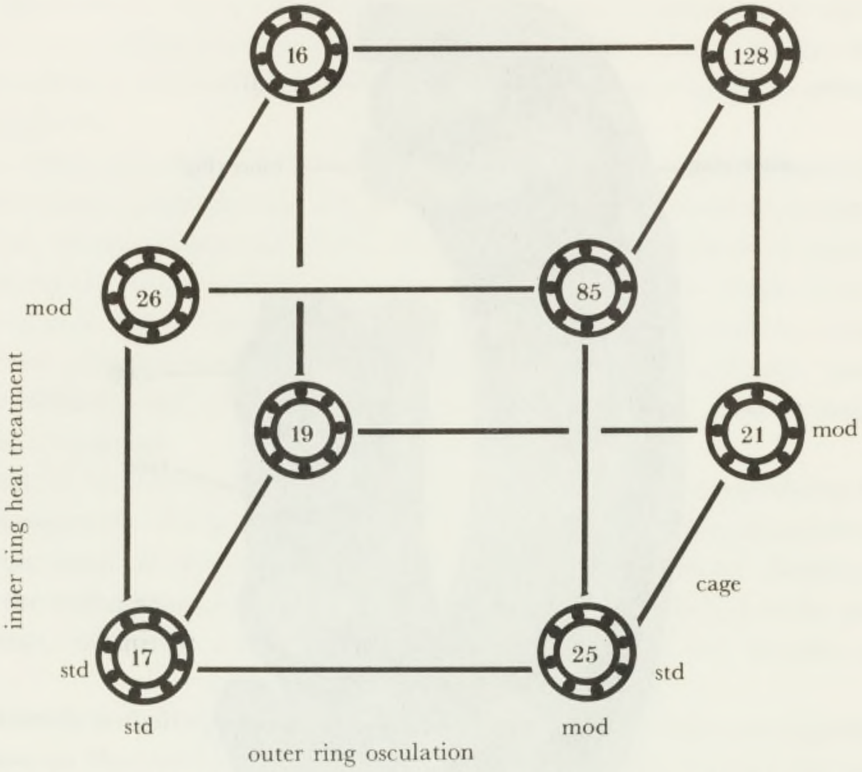

FIGURE 3. The number at each vertex of the cube represents the bearing's life (in hours).

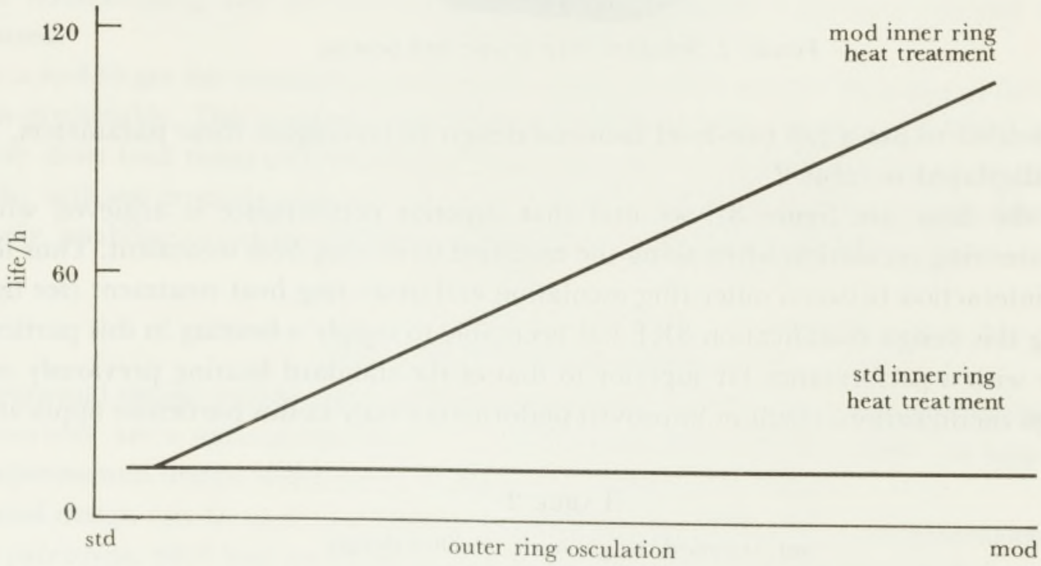

FIGURE 4. Graph showing the interaction between inner ring heat treatment and outer ring osculation.

The above-mentioned interaction was not previously known in the existing life theory for bearings, and it could only have been found by applying the factorial design technique of studying all variables at the same time.

Further, the analysis showed that the design of the cage did not have an effect on the performance of the bearing. This is very important information as use of one of these cage designs results in a reduction of the cost of the bearing.

In general, knowledge about non-contributory factors is very important, because such information often can be used to reduce the final product's cost.

Experimental design techniques can be used to solve problems related to the manufacturing process as well as problems related to product or prototype design. The limiting factor for the use of these techniques is really one's own imagination.

Introducing experimental design techniques company-wide will drastically reduce the time and effort spent on experimentation before reaching a conclusion, and ensure that there are no 'shots in the dark'. Further, when developing a new product or process, these techniques will enable a company to reach the market place with a better product much faster than if conventional experimentation were used. Employing and understanding these techniques will drastically reduce the risk of analysing and drawing conclusions from the 'wrong data'.

Conclusions

(i) SPC is an excellent tool for controlling manufacturing processes. This in turn will make it feasible to predict the outcome of the manufacturing process more accurately and thereby improve material flow, reduce work in progress and shorten lead times. The use of SPC is a crucial step towards 'just-in-time' production. Also, SPC provides a common language throughout an organization and allows the organization to effectively quantify and set priorities for improvements and investments.

(ii) Experimental design will enable us

to minimize the risk of analysing and drawing conclusions from the 'wrong data';

to reduce the cost and time for experimental work, and therefore help us to introduce new and better products faster to the market place;

to effectively study and optimize manufacturing processes;

to easily identify non-contributory variables which can then be used to reduce the overall cost of the product, thereby increasing profitability.

Discussion

A. D. Oosterhoorn (*Van Doorne's Transmissie B.V., The Netherlands*). Mr Hellstrand mentioned the award a plant receives when it produces the best performance in a particular year while applying SPC methods. In considering the annual appraisal system of workers, Dr Deming warned us not to discriminate between people and not to reward the 'above average' ones.

It is a property of a process with variability, and not necessarily a property of the individuals, that approximately half of the people perform 'above average'. The performance of individual plants in applying SPC can also be seen as such a process, so awarding the best performing plant might become a lottery.

Only the plants performing above or below control limits should be picked out and appropriate action taken. The responsibility of management is to improve the process, while rewarding individuals performing within control limits might increase the process variability.

C. Hellstrand. Any system of appraisal that does not take the inherent variability of the process into account is likely to be counter-productive. However, the award mentioned in my presentation is given to the two companies with the best implementation of SKF quality procedures together with the best production results. This competition recognizes and rewards the two best companies and, of course, puts some pressure on companies (if any) which are below the standard of the others. Adherence to SKF quality procedures is measured by a quality system audit conducted by a central audit group. In this audit the proper use and implementation of SPC is strongly emphasized.

D. J. Sherwin (*Department of Engineering Production, University of Birmingham, U.K.*). I am surprised that such an obvious candidate for SPC did not implement it until 1976. Could Mr Hellstrand comment on the position of maintenance *vis-à-vis* process capability in SKF?

C. Hellstrand. SPC was used at SKF at the end of the 1950s and again in early 1970s. On both occasions the use of SPC was not supported by top management because of a lack of understanding of the techniques, and consequently the implementation was not successful. This time the use of SPC is a priority for top management, hence its successful implementation.

Notes on the control charts indicate the reason for out-of-control situations and are used to prioritize areas where preventive maintenance should be used. Further, the effect of a preventive maintenance programme can be seen in the control charts as a decrease in the machine failure(s) targeted by the programme.

Also, before a machine is returned to production from maintenance, a capability test should be performed to ensure that the machine is ready for production (i.e. an 'acceptance test').

M. Gerson (*Industrial Statistics Research Unit, University of Newcastle upon Tyne, U.K.*). The capability and performance indices C_p and C_{pk} have been set up as measures of the ability of a process to produce material that conforms to the specifications. The use of the indices implies that random variation is assumed to be normal. More importantly, their use also assumes that what is being produced at any one point in time, or for any one batch, is representative of the whole variability of the process.

But there are many processes for which this is incorrect. For example, in the batch production of liquids individual batches may be relatively homogeneous. If we ignore for the moment the possibility of sampling and measurement error, then the single value that is used to measure location gives the value for the whole batch, and provided it is within the specification, no part of the batch is nonconforming.

We have also encountered processes that are run in campaigns. Initial adjustment of the process to within the specification may be difficult and costly, but once achieved the process can be run very consistently at that level. The customer is always getting material that conforms to the agreed specification, and yet a capability index calculated across a number of campaigns may look very poor.

In either case it may be neither necessary nor cost-effective to control the process much more tightly than required by the specifications, but the use of these over-simplified indices may make it appear that a supplier has insufficient control of his process.

C. Hellstrand. It is important to notice the difference between short-term and long-term capability studies (machine and process capability studies). C_p and C_{pk} are measures of the long-term capability of the process and should be based on data collected over an extended period of time, typically during a couple of days depending on the process. Further, data collection should not start until the process has been properly set up and reached a stable running condition.

Although these indices do not always tell the whole story, they will indicate where there is room for improvements. Also, as a customer, a supplier that can deliver 'identical' parts from time to time is regarded as a manufacturer of high quality products. Using a supplier with the ability to supply 'identical'parts will improve one's own production, resulting in a higher quality final product (cf. the Taguchi loss function).