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INFLUENCE OF RELIABILITY ON THE TRADITIONAL CONTROL CHARTS: A "RELIABLE SHEWHART CONTROL CHART"

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Abstract – The traditional control charts are based on the assumption that the measurement data relating to the average of each subgroup of the parameters under observation of a specific quality characteristic of product, process, system or service, are reported regardless of time stability of its own parameters. This condition is generally not verified in real cases, where we should take into account the lifecycle of measuring. In the case of monitoring of quality characteristic of a product for example, a parameter that is not in fact enjoy the property of time stability is its reliability, which is time-variant and it's decreasing over time in force of degradation to which the product is subject.

The traditional approach involves the construction of control charts with stationary limits, ignoring the possibility of an "adjustment" of those limits. This conceptual innovation determines the possibility of having an instrument to check, in a way as "tracking trajectory ", modulated on possible changes of the measuring. These variations may, for example, be due to degradation of the detained characteristics. The modelling for the scenario described is based on the implementation of reliability function, as a known source of the variability of control limits, as pre-determinable through the lifecycle of the product analyzed.

The results achieved through the proposed approach can improve the sensitivity of the monitoring instrument through the modulation of control limits, which thus acquires a beneficial discriminatory capacity, able to separate the effects of random variability arising from the common causes, from those owned to deterministic variability related to predictable changes of the measuring.

Numerical results, regarding an application to a manufacturing national company operating in the automotive sector, through fielded units taken in differing operating periods and tested, are reported.

Keywords: Control Chart; Monitoring; Reliability; Time Variant Conditions.

1. INTRODUCTION

Reliability prediction based on degradation modelling can be an efficient method to estimate reliability for some highly reliable parts or systems when observations of failures are rare. Degradation modelling is based on probabilistic modelling of a failure mechanism degradation path and comparison of a projected distribution to a pre-defined failure threshold. Consider the conceptual monotonically decreasing degradation path depicted in Figure 1. The failure mechanism is degrading probabilistically with time. At any specified time, there is a distribution of degradation measurements considering a population of similarly degrading parts. Note that in the figure the degradation measure has a larger variance as time increases. While this may not be representative of all failure mechanisms characterized by a decreasing degradation path, the increasing variance is often observed.

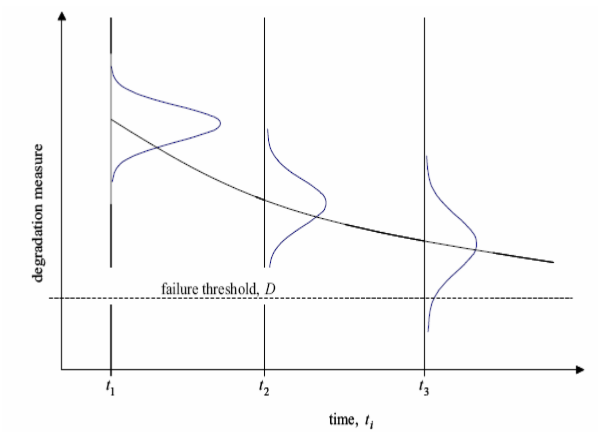

Fig. 1. Degradation path example

For any specified time, reliability can then be estimated as the probability that the degradation measure is greater than a critical threshold value. Alternatively, if the degradation path is monotonically increasing, then the reliability would be estimated as the probability that the degradation measure is less than the critical threshold value. To predict reliability based on degradation modelling, the failure mechanism must be clearly understood. The model parameters or coefficients can then be thought of as random variables for individuals within the population. Although the concept of reliability prediction based on degradation modelling is relatively recent, there have been several important and successful applications.

Here this approach would be applied to the control chart with the aim to modulate the control limits according to the different level of reliability that is possible to determine for different phases of a monitored process.

2. PROPOSED APPROACH

Relatively quick and accurate technique to predict the useful life of components is a critical tool to assure that future, and existing, product designs are successful in meeting warranty requirements. This need is particularly true for harsh environment equipments, such as in the automotive industry. However, understanding the direct relationship between field needs and environmental testing has been an elusive target for many years. Current lifetime prediction techniques require test data obtained over extended periods that approach actual module life. Furthermore, available field failure data is sparse and collected under uncontrolled conditions. For example, automotive products must operate satisfactorily under stressful environmental conditions. Environmental exposures include large temperature changes, constant vibration, long dwells at high temperatures and exposure to contaminants (e.g. automotive fluids, salt spray, etc.). Substantial environmental exposure variability in automotive modules creates a distribution of degradation patterns. For example, automotive electronics controllers are now located in the passenger compartment, firewall and mounted on or integrated within the engine/transmission system. Throughout these different locations, many different temperature ranges exist, with no set standard for each environment. This problem is compounded by the fact that vehicles containing these modules are located in many different areas of the world with varying ambient environments. In addition, driving patterns (e.g. commercial fleet service versus recreation, highway versus city, etc.) contribute to the variable environmental exposure. One solution to this problem is to study degradation patterns in a large sample of deployed assemblies returned from random field locations and compare the observed degradation with a failure threshold. The failure threshold is established from the behaviour of a performance variable with a predictable response obtained from accelerated laboratory testing. The minimum value of any predictable performance variable could be used as a basis for lifetime prediction.

Since the failure rate will be known, also will be known the reliability function R(t), which decreases exponentially with time, taking the trend of Figure 2.

Based on the assumptions taken into account the chart is amended presenting control variable limits, no more as ± 3σ (stationary), but in the form ± (3Kσ + k'σ), where

k = f [R (t)] and k '= Increase of tolerance.

In fact, it was taken in modelling system an increase of tolerance equal to 3σ of the further quantity k'σ.

Particularly, for a failure rate constant λ we have:

$$R(t) = e^{-\int_0^t \lambda(t)dt} = e^{-\lambda t} \qquad (1)$$

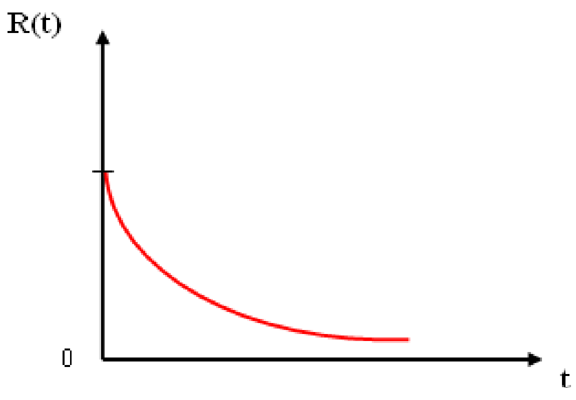

Fig. 2. Reliability Curve

Through the same rules for constructing a traditional control chart, but taking into account the assumptions made previously and the new variable control limits, we can build the "Reliable Control Chart".

It appears, qualitatively as reported in Figure 3.

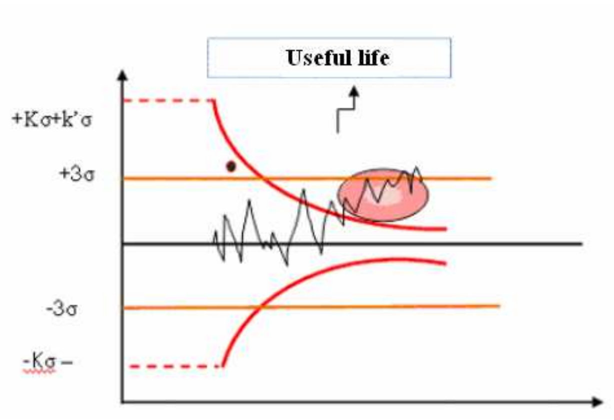

Fig. 3. Reliable Control Chart

The highlighted area in the figure 3 shows a situation out of control recognized by the "Reliable Control Chart", not by the traditional control chart. Once the function of reliability is known, then, through this chart is possible to make the control more severe (control limits characterized by a minor amplitude) where we expect a decrease of performances of the product (or system) monitored, and a more bland control where the theoretical performances are scheduled to be certified on high values. So the operative work conditions of a product or of a system are related to the project features.

Indeed, in the initial phase of monitoring, it is possible to detect out of control only through the traditional chart, while the out of control point is seen in control from the Reliable Chart. And it's normal because, the reliable chart is characterized initially by bland limits, as a consequence of a cost-benefit analysis, in fact in the initial phase the low probability of having an out of control does not justify corrective actions finalized to restore system to its nominal values, while, in the final phase the high probability justifies a more selective control.

Making control more severe implies an increase in costs that it's more advantageous avoid to support in the early phases of lifecycle of the product/process/system/service, because it is appropriate to make the control sensible to the reliability function, according to it, during his lifetime, the product works by reducing its performances over time.

3. EXPERIMENTAL RESULTS APPLICATION FOR A REALCASE (CONDOR GROUP S. P. A. COMPANY)

Presentation of the group of companies.

Condor Group, with all its companies, under its property and leadership of Petrosino's family, is involved in the production of composite materials, scaffolding, formwork, machinery and building block. The policy value creation and expansion, which in over twenty years of activity has led to the conclusion of important acquisitions, has allowed the achievement of leadership in the market in which the companies of the group operate.

Today the group owns seven production plants in Italy, a branch and a rental centre in France.

The group companies control all stages of the production chain, from shifting coil of steel to the profiling of the pipe, the assembly of the product lines completely automated. The production of equipment for transportation and construction in the last year has been integrated with a diversified and synergistic with it: the field events with the production of antlers, stands and audio-lighting towers for sport and show. The 2007 was the year of the debut in formworks.

Experimental Results.

We decided to experiment with the innovation introduced by the new implementation of the Quality Loss Function on one of the Brand Group, the Condor, or the area tubes. Condor is highly specialized in processing of steel coils (galvanized, pickled, hot rolled and cold) in the tube for the production of scaffolding, which in turn takes place in other brands of the group.

One of the needs in companies producing manufactured in composite materials is closely linked to meeting the technical specifications of physical endurance and / or chemical, depending on the particular product which the industry is intended.

It is evident that, given the deep differences between different products produced, each contract requires careful analysis about the choice of the type of resin used, the appropriate stratification of laminated composite materials and not least by the standards of time to time required by the developer.

For the experimental run ended, reference was made to measure of the hardness of surface profiles designed to pleasure craft, as shown in Figure 4.

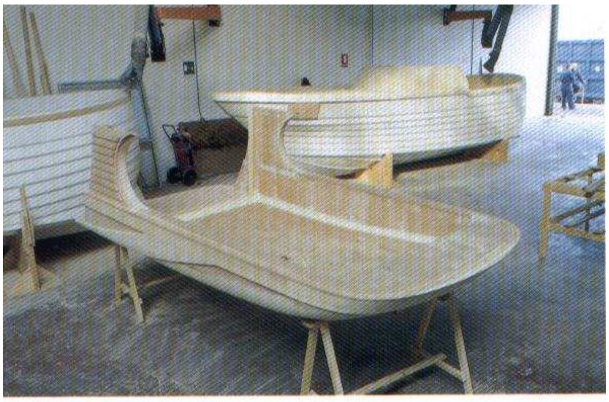

Fig. 4. Composite material for the experimentation

The use of reliable control chart starts when the product meets the function for which is demanded. In the examined case, the mission profile of the composite material used in coaches, is to resist the stresses and forces to load which is subject, with a value of surface hardness which allows it to function correctly, avoiding cracks and deformations.

Control of the surface hardness of composite materials examined, is measured during operation under certain operating conditions, and covers a period of approximately 3 years (period of operation).

The surface hardness measures taken relate to 10 sub-groups, each of 50 items, where, to estimate the standard deviation σ of the measurement process, for each section there were 3 measures of surface hardness.

Each subgroup has been inspected at an interval of time $\Delta t \approx 3$ months or so and the failure rate, $\lambda = 0.000375$, which is considered approximately constant in 3 years, it's a value given from the Quality Assurance sector of the Company taking into account the work cycle average of the items, corresponding to about (8 * 7) 56 hours per week.

Really, the traditional control charts do not take into account such long time for its monitoring, but the application example proposed aims basically to understand the evolution over time of the change of control limits, based on the function of product reliability under observation.

For each subgroup examined over time, it is estimated the average value in Barcol of measures surface hardness.

For i = 1, 2, ... 10 gives the values reported in table I

$\Delta ti \approx 3$ months	Average values μi
Δt1	92,4
Δt2	87,5
Δt3	87,1
Δt4	87,7
Δt5	88,9
Δt6	88,3
Δt7	88,5
Δt8	88,5
Δt9	87
Δt10	90

Table I. Average value in Barcol of measures surface hardness of each examined subgroup

The control chart realized will present on the control of the abscissa the time sampling of the various sub-groups, divided into intervals Δti, and on the axis of ordinate the average values for each subgroup.

The couple (Δti; μi) will be represented on chart by a control point.

It then calculates the average of averages, μtot = 88.59 Barcol (shown on the chart as a line parallel to the abscissa) and the standard deviation, which is considered constant, σ = 1.53.

Control limits stationary, typical for a traditional control chart, are given by:

- LCS (Upper Control Limit): μtot + 3σ
- LCI (Lower Control Limit): μtot - 3σ

The limits of control variables introduced in the proposed reliable control chart, are based on the implementation of the function as a reliable known source (on the curve of product life) of their evolution over time, taking into account, however, an increase of tolerance employed conveniently in cost-benefit analysis, as shown before:

LCSv (Upper Control Limit variable): μtot + 3Kσ + K'σ
LCIv (Lower Control Limit variable): μtot - 3Kσ - K'σ

For a failure rate of the product λ (t) constant, the reliability function R (t) takes on an exponentially decreasing trend, such that K = f [R (t)] = e-λt

Assume also, depending on the product concerned, a value of K '= 1.

It shows the evolution over time of the average values of the characteristic of quality control on control chart, by introducing the modifications on the model proposed.

The reliable control chart, for the experimental case examined, will be constructed as reported in figure 5.

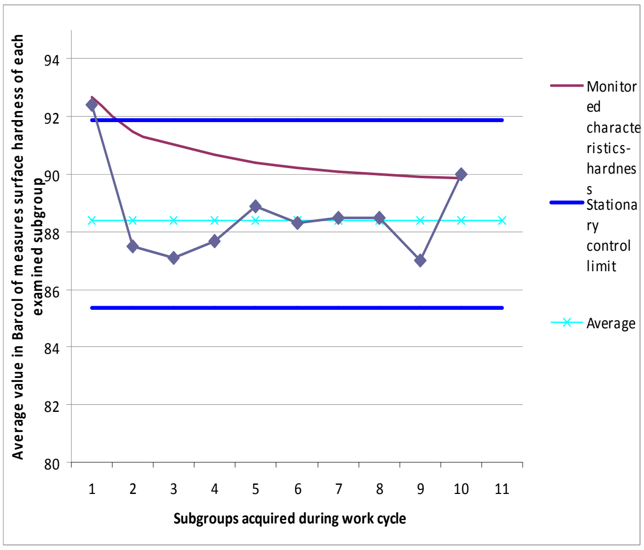

Fig. 5. Reliable Control Chart for the experimentation

Comparison between traditional control chart and reliable control chart.

Observing the graph of figure 5, is possible to consider that:

-1st point: the observation of the traditional control chart, unlike from the reliable control chart, would seem to be initially out of control.

The low probability of having an out of control (as indicated by the reliability function), it shows that the point checked on chart is an isolated point and hence the cost of an intervention to restore the system (in this case a rework of the composite material profile) does not is convenient.

-10th point: the observation of the traditional chart, unlike the reliable one, indicates a situation of control, whereas the system is reducing its performance, given the reliability function.

4. CONCLUSIONS

In this paper we propose an “adjustment” for the traditional control chart in terms of capacity to modulate the control limits according to the different level of reliability that is possible to determine for different phases of a monitored process. This opens up the potential to use Shewhart control charts, bringing enormous benefits in terms of enhancing the cost/benefits ratio of the process of restore of the system through corrective actions.

The implementation of this “adjustment” is possible once are known some reliability parameters of the measuring.

Numerical results relative to a real application of superficial hardness measures on composite materials are reported, regarding manufacturing national company operating in the automotive sector through fielded units taken in differing operating periods and tested.

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REFERENCES

[1] Lu CJ, Meeker WQ. Using degradation measures to estimate a time-to-failure distribution. Technometrics 1993; 35 (2):161–173.

[2] Sethuraman J, Young TR. Cumulative damage threshold crossing models. Reliability and Quality Control, Basu AP.

[3] Zuo MJ, Jiang R, Yam RCM. Approaches for reliability modeling of continuous-state devices. IEEE Transactions on Reliability 1999; 48(1):9–18.

[4] Lu S, Lu H, Kolarik WJ. Multivariate performance reliability prediction in real-time. Reliability Engineering and System Safety 2001; 72:39–45.

[5] Abdel-Hameed M. Failure models of devices subject to deterioration. Order Statistics and Non parametrics: Theory and Applications. Elsevier: Amsterdam, 1992; 307–313.

[6]. Campean IF, K¨uhn FP, Khan MK. Reliability analysis of automotive field failure warranty data. ESREL Conference Proceedings 2001; 3(2):1337–1344.

[7]. Wang Y, Jia Y, Yu J, Yi S. Field failure database of CNC lathes. International Journal of Quality and Reliability Management 1999; 16(4):330–340.

[8]. Montgomery DC. Introduction to Statistical Quality Control (5th edn). Wiley: New York, 2005.

[9]. Devore JL. Probability and Statistics. Duxbury: Pacific Grove, CA, 2000.

[10]. Tobias PA, Trindade D. Applied Reliability. Van Nostrand Reinhold: New York, 1986.

[11]. Nelson LS. A control chart for parts-per-million nonconforming items. Journal of Quality Technology 1994; 26(3):239–240.

[12]. Borror CM, Montgomery DC, Runger GC. Robustness of the EWMA control chart to non-normality. Journal of Quality Technology 1999; 31(3):309–316.

[13]. Shewhart WA. Economic Control of Quality of Manufactured Product. Van Nostrand: Princeton, NJ, 1931. John Wiley & Sons, Ltd. Qual. Reliab. Engng. Int. 2006; 22:733–755

[14]. Burr IW. The effect of non-normality on constants for $\bar{X}$ and R charts. Industrial Quality Control 1967; 23(11):563, 566–569.

[15]. Chan LK, Hapuarachchi KP, Macpherson BD. Robustness of $\bar{X}$ and R charts. IEEE Transactions on Reliability 1988; 37(1):117–123.

[16]. Schilling EG, Nelson PR. The effect of non-normality on the control limits of $\bar{X}$ charts. Journal of Quality Technology 1976; 8(4):183–188.

[17]. Yadav OP, Singh N, Goel PS. A framework for reliability prediction during product development process incorporating engineering judgments. Quality Engineering 2003; 15(4):649–662.

[18]. Chan CK, Tortorella M. Confidence intervals for hardware reliability prediction. Case Studies in Reliability and Maintenance, Blischke WR, Murthy DNP (eds.). Wiley: Hoboken, NJ, 2003.

[19]. Burr IW. Control charts for measurements with varying sample size. Journal of Quality Technology 1969; 1(3):163–167.

[20]. Nelson LS. Standardization of Shewhart control charts. Journal of Quality Technology 1989; 21(4):287–289.

[21]. Nelson LS. Setting up a control chart using subgroups of varying sizes. Journal of Quality Technology 1990; 22(3):245–246.

[22]. Nelson LS. Shewhart control charts with unequal subgroup sizes. Journal of Quality Technology 1994; 26(1):64–67.