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Maintenance Diagnosis Methodology Based on Metrological Characteristics, Statistical Process Control and FMEA Analysis

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ABSTRACT

This paper presents a research aiming at the maintenance optimization applied in a company producing wirings. Information about machinery status from measurements of realized items are used, including data that at first does not seem to have any correlation with the efficiency condition of the single component. These observations have been correlated with the various process weaknesses by FMEA analysis and with the past maintenance activities and their results, in an integrated approach of Statistical Process Control, FMEA, Failure Log and RCM (Reliability Centered Maintenance). The indicators trends may be monitored with reference to stated limits (as in the control charts method) and can become the main rule to activate maintenance procedures and pre- alarm signals. The purpose is to define a coherent and complete set of criteria and indicators making able to detect the machines deterioration that can affect, in particular, safety and quality.

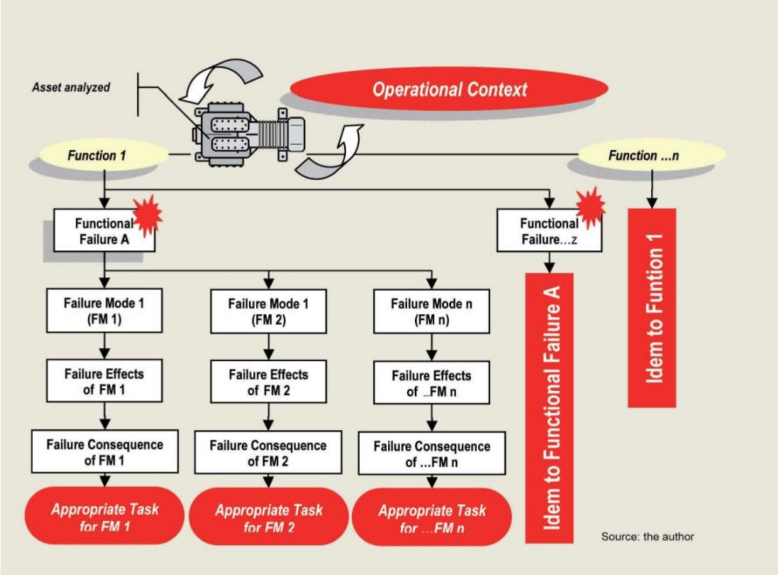
Keywords: RCM Reliability Centered Maintenance, FMEA Failure Mode and Effect Analysis, SPC Statistical Process Control.

1. Introduction

Maintenance management can become an important opportunity to obtain a large number of advantages. A good plant and machinery maintenance can improve product quality, workers safety and environment protection. The main advantages of an effective maintenance process concern the cost reduction, due to efficiency losses, product quality assurance, improvement of machinery performances and prevention of accident at work.

2. Method

The main target of a RCM (Reliability Centered Maintenance) process is the possibility to assure that the systems' availability is always aligned with the requirements of the process owner or user. The standard SAE JA 1011 defines the requirements of a RCM maintenance process. Usually, it is adopted a methodology proportionate to the consequences of the failure modes.



Source: the author

Figure 1

Failure modes can be defined as the events that cause the damages and the malfunctioning of the system. This means that, due to technical or human mistakes, failures can affect the system or a part of it and it is important their identification and analysis. The RCM process begins with a FMEA (Failure Mode and Effect Analysis). In a following step, by the analysis of any possible failure mode, the maintenance activities are defined. These elements determine if the maintenance activity is appropriate to the failure mode, as shown in figure 1.

The RCM points out four categories of consequences that can derive from a failure mode, allowing evaluating its importance. In a priority order:

- Consequences for safety
- Consequences for the environment
- Consequences for the operation and quality
- Non-operational consequences (e.g. maintenance costs)

Analyzing the consequences of the failure mode under exam, it is possible, by a decision-making process, to find out the most suitable maintenance process (predictive, on condition, preventive, etc.) that can minimize or avoid the failure mode consequences. The possibility to predict the maintenance needs by the metrological characteristics of the product, is based on this assumption: if a maintenance need has effects on the product, it is possible that it has a recognizable influence on the trend of the characteristics during time. In other words, it should be necessary to discover the relationship between the production system’s maintenance needs and its process capability.

3. Research

The research has been developed in a company producing wirings for automotive, telecommunications, data transmissions, industrial electronics and transports and is based on the analysis of the data automatically collected by the software TopWin on a cut – seam folding machine (Komax Gamma 333 PC, precision +/- 1mm or <0,2%). The machine log is automatically generated by the software TopWin that allows the control of some working parameters of the machine that are recorded as html files. The files here considered are the “Production State Data” and the “Machine Error Data”.

3.1 Production state data

This log contains any information collected in sequence from the machine. These information concerns:

- State of the machinery (start/pause/resumption/stop of the production
- ArticleKey
- UserName
- Wire type, total length before and after the manufacture

Eg.: Wire = HB 1, 7249655, 7223995

- Cable terminal type, number of terminals applied before and after the manufacture.

Eg.: Terminal = 1.08278.54, 5994, 5900

- Crimp Height

Eg.: CrimpHeight = HB 1, 1.23903.90, TRUE, 1.608

The first term indicates the wire type. The second term indicates the code of the crimp terminal and therefore of the tool used. The third term is a logical value that indicates if the manufactured product conforms to the requirements. The fourth term is the wire measure in mm.

- Pull Off force

Eg.: PullOffForce = HB 1, 1.23903.90, TRUE, 203.0

The last term indicates the unthread force after the destructive test.

The crimp height and the pull off force are measured on the first article manufactured, before starting the lot production. If one of the 2 values is out of the prescribed tolerance, a new sample is manufactured and tested. If it is necessary to repeat several times the sample manufacture, that means, probably, that the operator has to change the air pressure on the crimp tool or to carry out a maintenance intervention. During the lot production only the height of the stop-point of the tool's punch is controlled. In order to check the unthread force, destructive sample tests are done, using digital dynamometers.

The following list shows, as example, the production lot of 8 wires with crimped terminals on each end; it is registered the deviation, in hundredth of mm, from the nominal value. These values and the crimp force are displayed in real time for each piece manufactured.

3.2 MeasurementsLeadSet1 (08:27:25)

- TerminalEnd1 = 1, TRUE, -7
- TerminalEnd1 = 2, TRUE, -11
- TerminalEnd1 = 3, TRUE, 2
- TerminalEnd2 = 1, TRUE, -12
- TerminalEnd2 = 2, TRUE, -2
- TerminalEnd2 = 3, TRUE, -1
- TerminalEnd2 = 4, FALSE, 73
- TerminalEnd2 = 5, TRUE, 18
- TerminalEnd2 = 6, TRUE, 27
- TerminalEnd2 = 7, TRUE, 29
- TerminalEnd2 = 8, TRUE, 42

The trend of these values can be an index of the effectiveness state of the machine and of the tool. A drift of these values can indicate a malfunctioning of the machine's pressure circuit, as it means an overpressure or an under pressure applied on the crimp tool; in this case there may be problems in the conditioning unit of the machine (taps, valves, etc.).

If the displayed pressure value is within the acceptable tolerance, the anomalous trend is due to the tool wear-out and it would be necessary to replace it.

Statistical Process Control allows assessing the capacity of a process in the industrial field; in particular, numerical parameters that allow evaluating how much a production process, characterized by its own statistical variability, can satisfy a production specification are:

$$C_p = (L_{ss}-L_{is})/6\sigma$$

Where, L_{ss} is the upper limit of the specification, L_{is} the lower limit and σ is the standard deviation of the values generated by the process.

With a statistically significant number of measurements or surveys, it is observed that the values generated by the process under examination will tend to assume a Gaussian distribution; this distribution is characterized by an average value (X) and by a standard deviation value (σ).

If the mean value of the x distribution does not coincide with the nominal value of the specific μ, two capacities ("upper" and "lower") can be calculated, each referring to one half of the Gaussian distribution:

$$C_U = (L_{ss}-x)/3\sigma$$

$$C_L = (x-L_{is})/3\sigma$$

considering the lower value between C_U and C_L as capacity Cpk

The Cp and Cpk indexes are constantly controlled.

For example:

- TerminalCPEnd1 = **1.03278.44, 6.3, 2.0**
- TerminalCPKEnd1 = **1.03278.44, 5.3, 2.0**

The second term is the Cp or Cpk value of the lot, while the third value indicates the Cp or Cpk of the whole production from the last reset to the end of the analyzed lot.

3.3 Machine error data

This file concerns the information on a malfunctioning of the machine and it refers to the error signals (FALSE) present in the "Production State Data" file.

4. Results

Using the data of the "Production State Data" file, an analysis on a sample period of 10 days, from January 2nd to 15th, has been developed.

Step number 1

The information used in the first step concern:

- the values of the relative crimp height (height of the stop point of the tool’s punch with reference to the set “zero” value);
- Cpk of the single lot
- Cpk calculated from the last production reset to the end of the examined lot

4.1 Dispersion graphs of the crimp values

Considering the crimp height values as a function of the progressive number and referring to the crimped terminal (T1 or T2), it is possible to obtain the graphs that put in evidence the trend of the daily machine production, in order to point out the values that have anomalous deviations from the reference values. For example, the crimp height dispersion graphs can give an estimate of the production variance and the number of the defective products (figures 2 and 3).

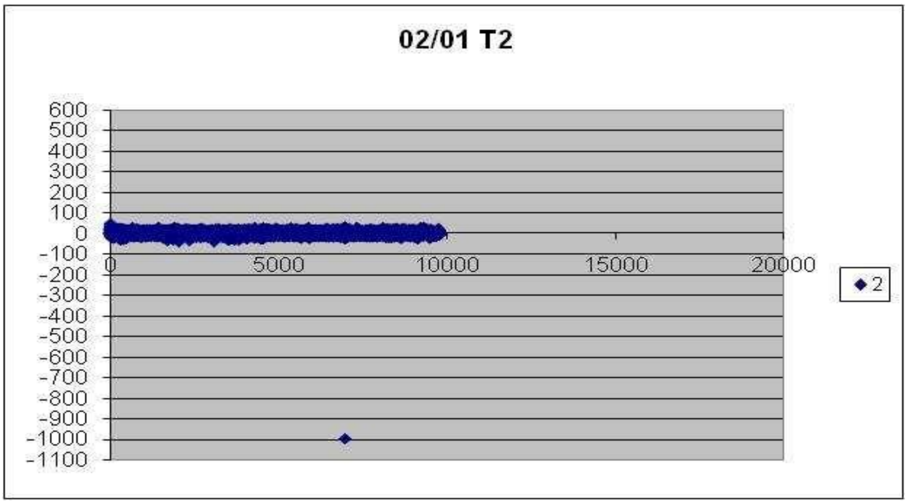


Figure 2

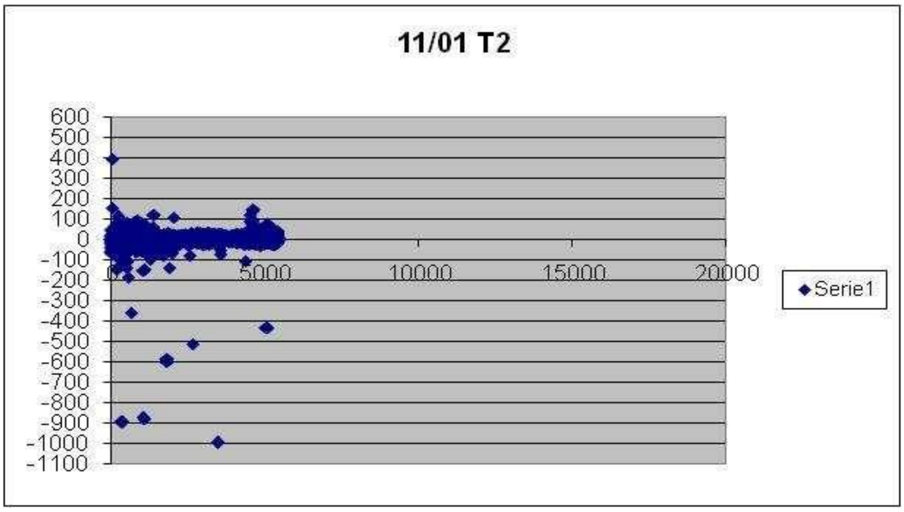


Figure 3

The dispersion graph of Figure 2 shows a trend near to the ideal one, while the trend in Figure 3 denotes the presence of malfunctioning that cause a lack of precision in the crimp height. This analysis cannot give detailed information, but can establish the base for following analysis. In these analysis, the study of the periods that show high variances (and the former ones) usually locates the parameters that can predict a future malfunctioning.

4.2 Cpk Trend

Following the dispersion analysis on crimp values, the relevant Cpk values, calculated in the “production state data”, are elaborated. In a graph (Figures 4 and 5) are showed the Cpk value of each lot (blue line) and the Cpk value relevant to all the pieces that have been manufactured from the starting of the production until the end of the examined lot (red line).

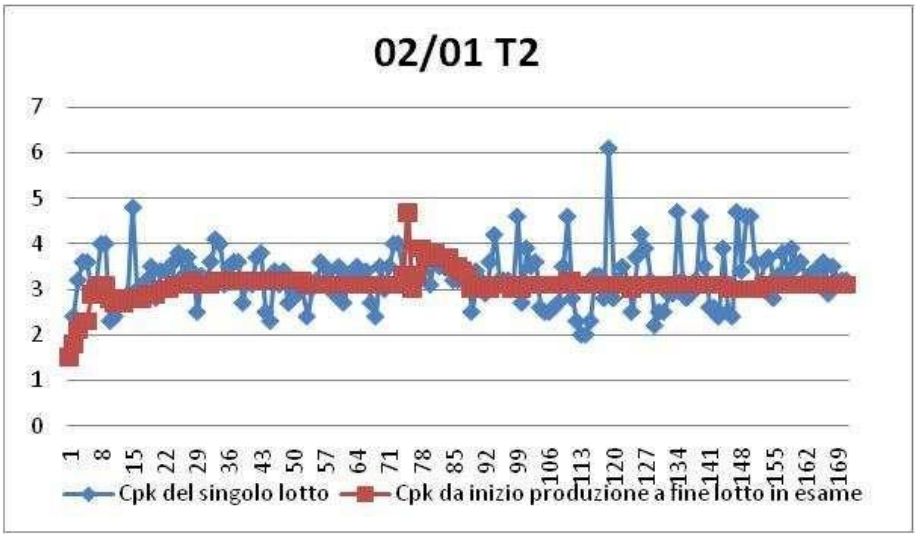


Figure 4

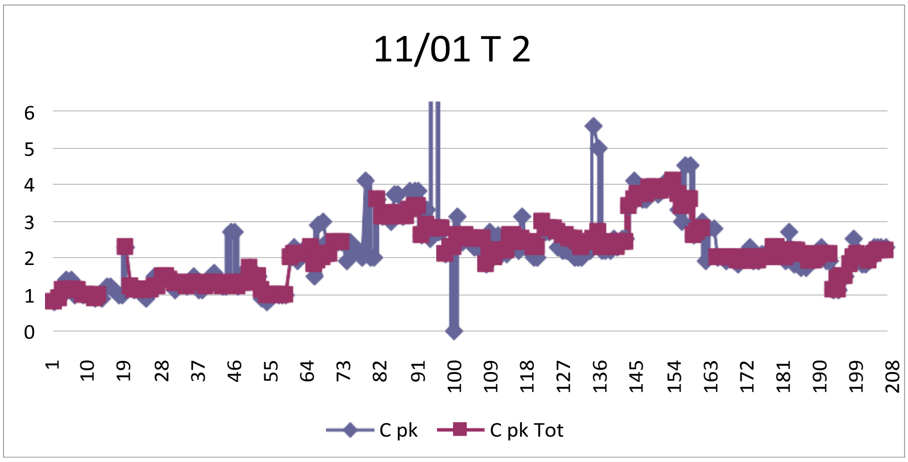


Figure 5

The Cpk trends confirm what has been showed in the previous graphs, adding an important information relevant to the process capability and drift. If we locate, through the dispersion graphs, a day in which there is an anomalous values concentration, confirmed by extremely low Cpk values, the Cpk analysis of the previous days could give useful information to our survey, making possible, in this way, a capability trend analysis. If we consider, for example, January 11th, there is a very high values fluctuation in the dispersion graph (Figure 3), while the Cpk values are quite low, especially at the beginning of the production (Figure 5).

Therefore, to continue our analysis, it will be necessary to use the dispersion graph and the Cpk graph, related to the previous days, trying to get useful information for our research.

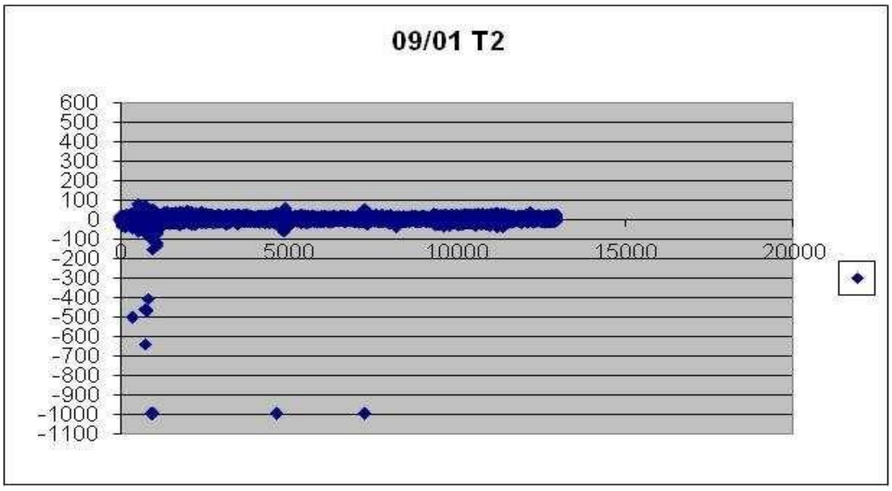


Figure 6

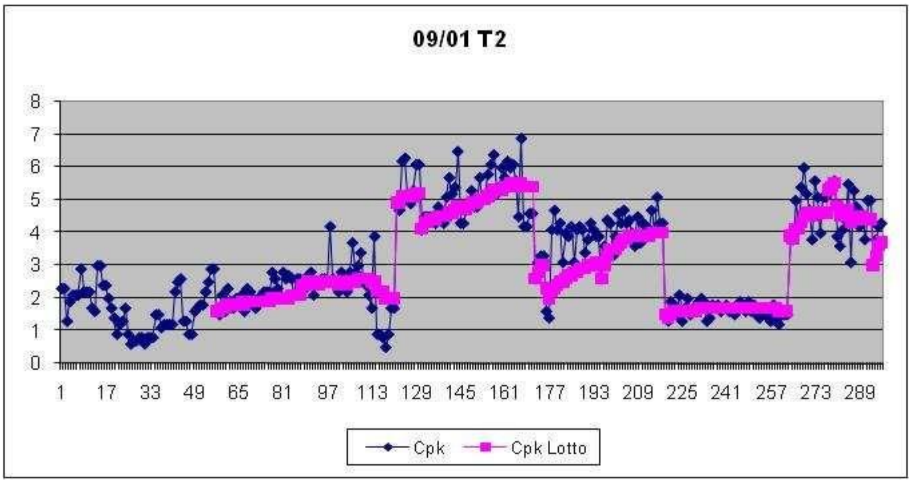


Figure 7

From the dispersion graphs it is not possible to collect, in this case, any important information, excluding the presence of some out-of-tolerance values at the beginning of January 9th (Figure 6) and a sudden variance increase at January 10th, at the end of the production (Figure 8). The Cpk graphs give more information: at January 9th, for example, the values show a swinging trend (Figure 7). Analyzing the “production state data”, it is possible to remark that this particular trend is due to the use of different crimp tools during the production. In particular, at January 9th, the terminals whose crimp tools have Cpk values below the acceptable limit are those indicated by the codes:

1.20648.441 (Cpk between 0,6 and 2,9) used in the initial production.

1.03158.54 (Cpk between 1,3 and 2) related to the second-last step in Figure 7.

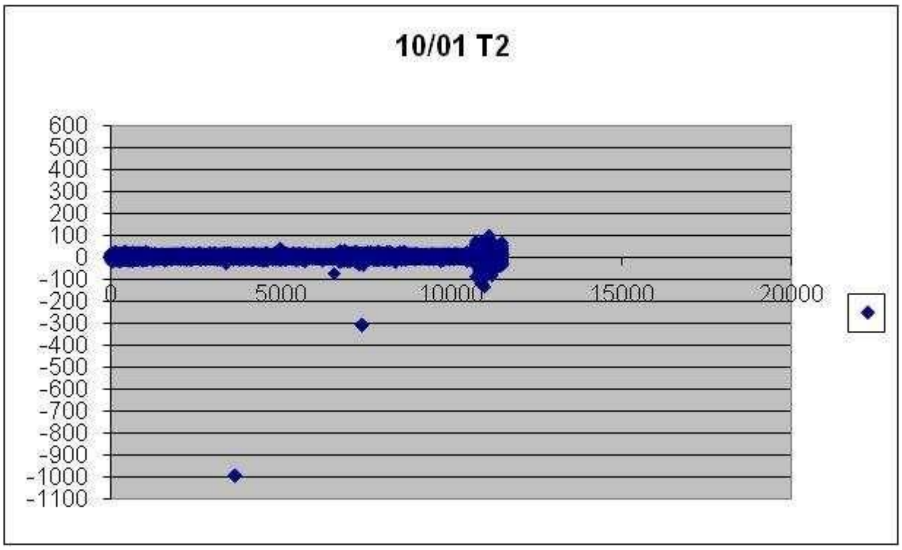


Figure 8

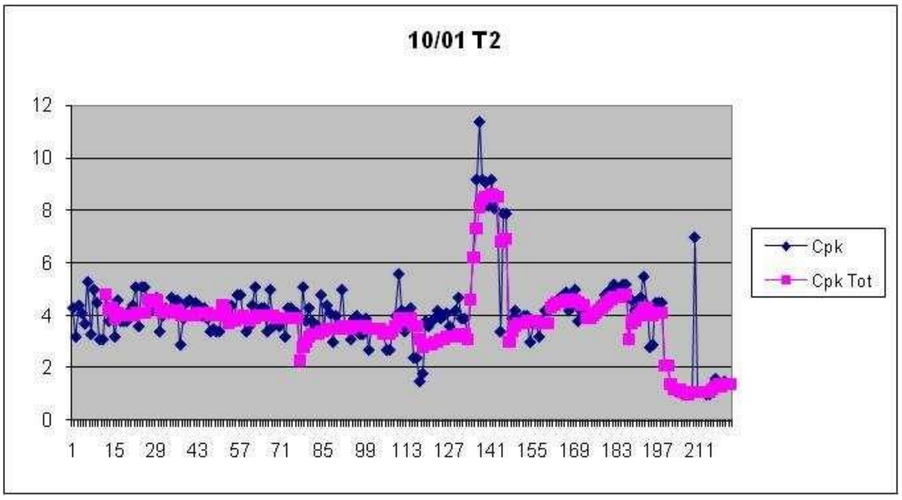


Figure 9

[1]It has been verified that the code 1.20648.44 kind of crimp tool used for the second time and, therefore, probably subject to a high failure rate due to the "infant mortality".

In January 10th (Figure 9), after the peak values found during the application of the terminal 1.24833.44, the Cpk values decrease considerably at the end of the shift, when the terminal 1.08250.54 has been used. In January 11th, it is possible to notice that, although the dispersion graph (Figure 3) seems to show a remarkable malfunctioning during the whole shift, the Cpk graph (Figure 5) points out alarm values only at the beginning of the production; analyzing the "production state data", it is possible to note the correspondence with the crimp tool 1.08250.54 terminal application, the same that has caused the Cpk values downfall in the previous day. It is remarkable that the apparently flat trend of the Cpk graph is due to the above mentioned reasons (Cpk calculated on the progressive lot and not on the product). In particular, the terminal 1.08250.54 lots, although they seem to be few in comparison to the daily production, they contribute to almost the half of the daily production, as they have a large numerousness.

4.3 Backward analysis

Once pointed out the detective tool, in order to verify the possibility to do a predictive analysis based on the available data, that precede the failure state, a backward analysis has been handled, to point out the days in which the examined machine has used the terminal tool 1.08250.54. The available data cover a period from October 2007, in which the TopWin system has been installed, and it has been possible to point out only one previous application of the above mentioned terminal, on December 14th.

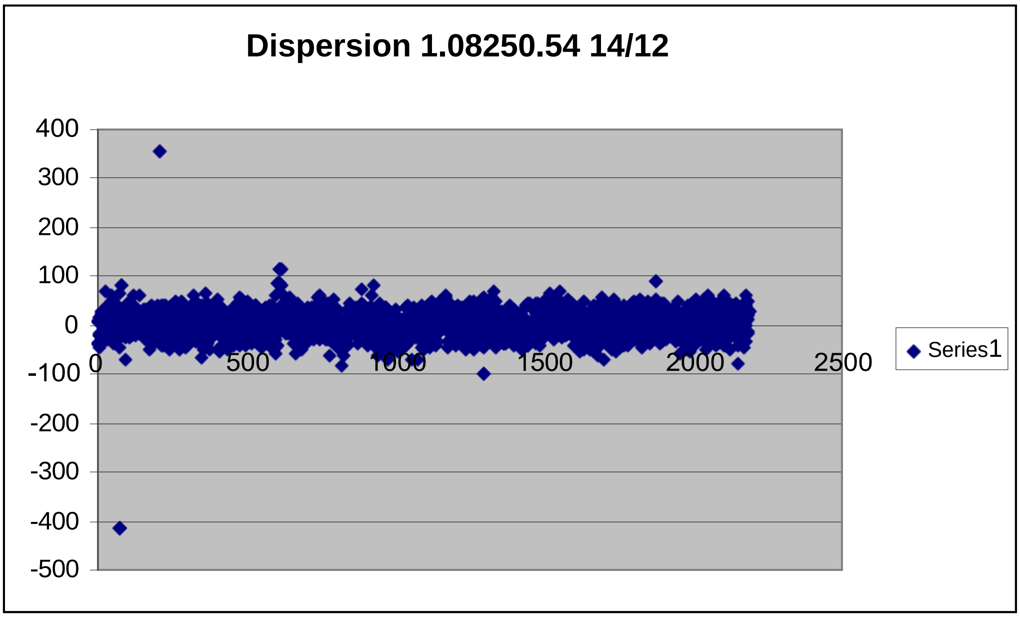


Figure 10

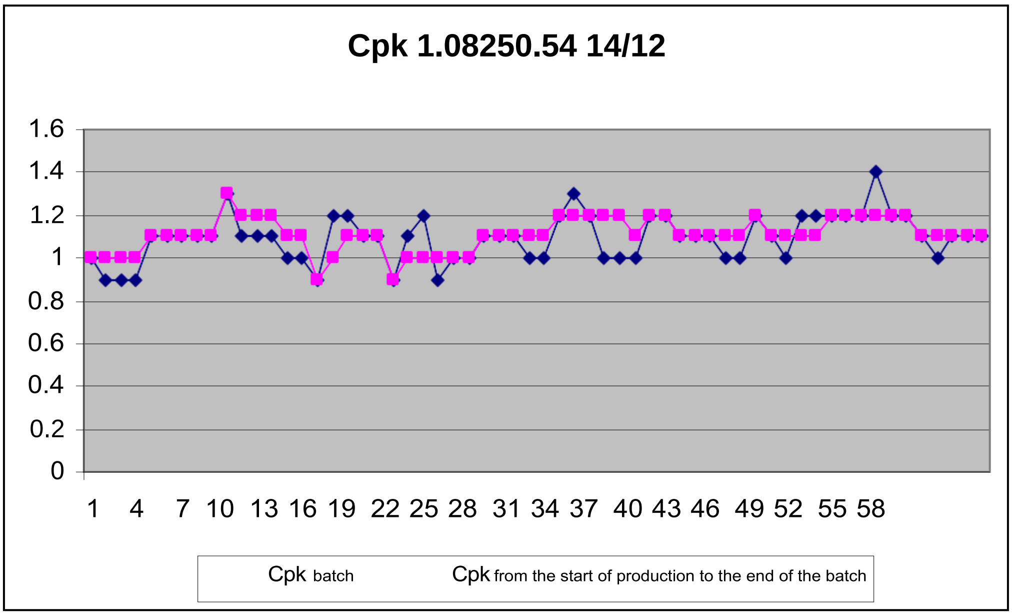


Figure 11

The Figures 10 and 11 shows that the dispersion graphs of the crimp height and of the Cpk, calculated on that values for each lot, pointed out an unsatisfactory value trend. Therefore, it is possible to state that the too high variability found in the dispersion graphs of January 11th has been caused by the unacceptable wear-out state of the tool and that it should be possible to point out a decrease trend of the Cpk values and a deviation increase in the dispersion graphs. Fixed an alarm value (for example Cpk = 1,66) it should be possible to start a predictive maintenance activity. It is also necessary to point out that the examined machines have been installed less than two years ago, that the detailed maintenance plan of the machine user’s manual and the real-time regulation possibilities of some process parameters by the operator, make the crimp tools the first components that are analyzed, as their useful life is considerably lower than the other machine components.

Step number 2

The production situation has been examined more closely, aiming at collecting more precise information and verify the starting assumptions, by the analysis of other parameters contained in the “production state data” and related to the sample produced when a new kind of terminal is crimped. As the data processing is quite difficult, we have examined, first of all, the crimp tools that have presented malfunctioning. The examined values are:

- Crimp Height: the seam height (in mm) on the unsheathed wire (in absolute value and not gathered form the stop height of the punch)
- Pull off Force: unthread force (in N) measured in destructive tests.

The results are important for the continuation of the production. As a matter of fact, if they don’t fulfil the fixed values, the operator will adjust the process parameters and new samples will be created until the measurement will be positive. We could believe that using these two kinds of values (Crimp height and Pull off force) is enough to make a predictive analysis, but it should also be considered that the positive test on the sample is a necessary but not enough condition to consider correct the crimp tool operating way.

Let’s examine some data to confirm what we have stated.

January 9th **DoubleCrimp CrimpHeight**	**M 1.5 M 1.5**	**1.20648.44**	**TRUE**	**2.548**
DoubleCrimpPullOffForce	M 1.5 M 1.5	1.20648.44	TRUE	**543.0**
CrimpHeight	NZ 0.75	1.03158.54	TRUE	**1.115**
PullOffForce	NZ 0.75	1.03158.54	TRUE	**153.0**
January 10th **CrimpHeight**	Z 0.50	1.08250.54	FALSE	**1.269**

CrimpHeight	Z 0.50	1.08250.54	TRUE	**1.104**
PullOffForce	Z 0.50	1.08250.54	FALSE	**66.0**
PullOffForce	Z 0.50	1.08250.54	FALSE	**81.0**
PullOffForce	Z 0.50	1.08250.54	TRUE	**91.0**
January 11th **CrimpHeight**	BN 0.50	1.08250.54	TRUE	**1.195**
PullOffForce	BN 0.50	1.08250.54	FALSE	**85.0**
PullOffForce	BN 0.50	1.08250.54	FALSE	**86.0**
PullOffForce	BN 0.50	1.08250.54	FALSE	**87.0**
PullOffForce	BN 0.50	1.08250.54	FALSE	**87.0**
PullOffForce	BN 0.50	1.08250.54	FALSE	**81.0**
PullOffForce	BN 0.50	1.08250.54	FALSE	**77.0**
PullOffForce	BN 0.50	1.08250.54	FALSE	**82.0**
PullOffForce	BN 0.50	1.08250.54	FALSE	**89.0**
PullOffForce	BN 0.50	1.08250.54	FALSE	**88.0**
PullOffForce	BN 0.50	1.08250.54	TRUE	**94.0**
December 14th *** CrimpHeight**	Z 0.50	1.08250.54	FALSE	**1.272**
*** CrimpHeight**	Z 0.50	1.08250.54	TRUE	**1.088**
*** PullOffForce**	Z 0.50	1.08250.54	FALSE	**89**
*** PullOffForce**	Z 0.50	1.08250.54	FALSE	**77**
*** PullOffForce**	Z 0.50	1.08250.54	FALSE	**84**
*** PullOffForce**	**Z 0.50**	**1.08250.54**	**TRUE**	**96**

It is immediately evident the high number of samples with the terminal 1.08250.54, produced within January 10th - 11th and December 14th, that have been considered nonconforming. From the “production state data”, concerning January 9th it is possible to see how, although the dispersion and the Cpk graphs shows nonconforming situations in the 1.20648.44 and 1.03158.54 terminal application, the tests on the sample gave positive results already from the first measurement.

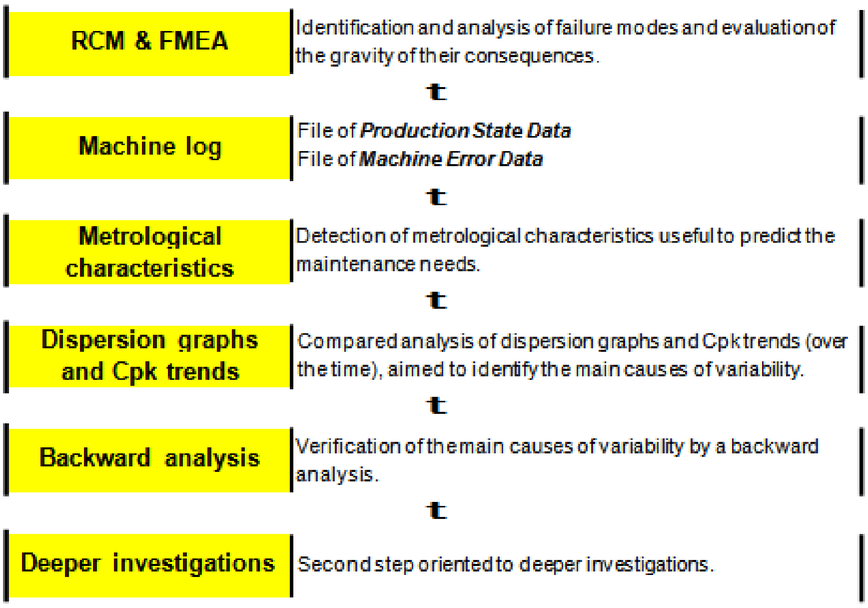


Figure 12

5. Conclusions

A satisfactory analysis can also be done on the base of data that, considered one by one, does not seem to have any correlation with the efficiency condition of the single component. To carry out this kind of analysis, it is necessary an adequate knowledge of the machine system, but it is even more important to define a precise framework of the possible interrelations within the available data. For this purpose, a standardized approach is essential. The steps here suggested are summarized in Figure 12, where the integration of many methods is highlighted.

A data processing like to the one previously analyzed, requires a great quantity of tests. The production process presented in this paper has considered a daily production of about 20,000 pieces and, therefore, we have presented only a quite short period, having determined the assumptions for the most complete analysis. It is also necessary to underline that a failure imminence prediction cannot leave out of consideration other parameters (as visual checks), that are permanently controlled by the machine operator, even if they are not registered in the data processing system. In conclusion, we believe that we have identified an effective method to link SPC, FMEA and RCM together in order to give intervention criteria to those who have to make quick decisions in the production scope.

Declarations

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Competing Interests Statement

The authors declare no competing financial, professional and personal interests.

Consent to participate

Not Applicable

Consent for publication

We declare that we consented for the publication of this research work.

Availability of data and material

Authors are willing to share data and material according to the relevant needs.

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