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RESEARCH ARTICLE

Identification of the out-of control variable(s) in the process of producing Needle valves in gas industries

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Abstract

Multivariate statistical quality control is one of the branches of statistical process control which is quickly under the development. Now a days in the most industries we are encountered with the conditions in them multi dependent characters must be controlled concurrently. In this article, the control of several variables is used practically in the production line of Needle valves in gas industries. By paying attention to the correlation of the exiting variables, it seems essential to use from these multi-variables controlling, and then, after making the historical Data, and estimating the parameters, the T^2 control chart construct for new observations from process, and then we can identify the out-of-control observations, and finally by using MYT algorithm, the deviation variable(s) in this observations is detected. Then by studying the process, the reason of deviation were recognized and finally several methods were introduced in order to improve the process in two parts which including the improvement in work instruments and the technical structure of Needle valves.

INTRODUCTION

A big problem in using the statistical multivariable charts[5] is the interpretation of the signed points. This incident is the result of use attempt to reduce the p-dimensional vector data to the univariate statistic. The reducing dimension of the data often cause to hidden the reasons of signed observation and the researchers become disappointed to use these multi variable techniques.

In the multivariate statistical process control (MSPC)[1,4,6,18,19] one out of control observation can be occurred by different situations. It is possible, for example, that one of the p existing variable, in one observation, has been out-of control, and consequently this point is out of control limits, or the relationship between two or more variables is not conforming to relationship with other variables as established by the historical data set. It is possible, a signed point, because of the combination of those mentioned conditions is made, too. It means that some variables are out of control and some of them have a wrong relationship with each other. a few methods have been introduced regarding to interpret the signed points which one of the best method is the Mason, Tracy and Young (MYT)[7-17] decomposition of T^2 statistic.

Reviewing on the MYT decomposition of T^2 statistic

To construct the multivariable shewhart charts[1] for a process in second phase, the Hotelling's T^2 statistic[2] is used as following:

$$T^2 = (X_f - \bar{X})' S^{-1} (X_f - \bar{X})$$

Where $\bar{X}$, S are the mean vector and covariance matrix estimators[20], which are calculate from the first phase data (reference sample) and X_f is the new observation vector in the second phase of the system. In relation to the identification of the deviation variable(s) in the out of control observation ,Mason, Tracy and Young had introduced a MYT decomposition of T^2 statistic which by this method we can decompose the Hotelling's T^2 statistic into independent and orthogonal parts that each ones shows the distinct proportion of each variable from T^2 statistic. For a p-dimensional vector, one form of the MYT approach can be expressed as 7,9

$$T^2 = T_1^2 + (T_{2.1}^2 + T_{3.1,2}^2 + \dots + T_{p.1,2,\dots,p-1}^2)$$

$$= T_1^2 + \sum_{j=2}^{p} T_{j.1,2,\dots,j-1}^2$$

It is certain that the above subdivision is not unique and different p! subdivision can be produced that each one has p partitions (conditional and non-conditional terms). The first term (non-conditional terms) of this decomposition can be shown generally as T_j^2 for j=1,…,p , which in fact the same square of the univariate statistic of the t student for jth variable of x vector and has F distribution as the following form:

$$T_j^2 = \frac{(X_j - \bar{X}_j)^2}{S_j^2} \sim \frac{(n+1)}{n} F_{1,n-1,\alpha}$$

The conditional terms $T_{j.1,2,\dots,j-1}^2$ for j=1,…,p is in fact the same jth variable which is adjusted by the conditional mean and variance and its exact distribution is as follows

$$T_{j.1,2,\dots,j-1}^2 = \frac{(X_j - \bar{X}_{j.1,2,\dots,j-1})}{S_{j.1,2,\dots,j-1}^2} \sim \left[\frac{(n+1)(n-1)}{n(n-k-1)}\right] F_{1,n-k-1,\alpha}$$

Where k is the number of conditional variables and the mean of the conditional jth variable can be obtained by the following equation:

$$\bar{X}_{j.1,2,\dots,j-1} = \bar{X}_j + b_j'(X^{(j-1)} - \bar{X}^{(j-1)})$$

and $\bar{X}^{(j-1)}$ is the $(j-1)th$ vector excluding the jth variable, $\bar{X}_j$ is the sample mean of the *jth* variable, $X^{(j-1)}$ is the $(j-1)th$ vector of process data excluding the jth variable and $b_j = S_{XX}^{-1} s_{xX}$ is a $(j-1)th$ dimensional vector estimating the regression coefficients of the jth variable regressed on the first $(j-1)$ variables,

$$S_{j.1,2,\dots,j-1} = s_x^2 - s_{xX}' S_{XX}^{-1} s_{xX}$$

and

$$S = \begin{bmatrix} S_{XX} & s_{xX} \\ s_{xX}' & s_x^2 \end{bmatrix}$$

The conditional terms can be used to check whether the jth variable is conforming to the relationship with other variables as established by the historical data set, since the adjusted observation is more sensitive to changes in the covariance structure.

Although, the MYT decomposition method has used as a kind of powerful method to interpret the signed points and to identify the out-of-control variables, but of the difficulties of using this method, is doing the several numerical estimations which can be time-consuming and boring. Since by increasing the number of variables, the number of the terms by MYT decomposition are increased progressively. In order to solve this problem we can use the computer programs to do the estimations and identify the meaningful terms.

In this project, the Qualstat software is used to compute all the conditional and non-conditional terms which are obtained from MYT decomposition of T^2. The following is a sequential computational scheme that has the potential of further reducing the computations to a reasonable number when the overall T^2 signals, as was proposed by Mason, Tracy and Young (1997)[9] .

Algorithm steps

Step 0. Conduct a T^2 test with a specified nominal confidence level if an out-of control condition is signaled then continue with the step 1.

Step 1. Compute the individual T^2 statistic for every component of the *X* vector. Remove variables whose observations produce a significant T_i^2. The observations on these variables are out of individual control and it is not necessary to check how they relate to the other observed variables. With significant variables removed we have a reduced set of variables. Check the sub vector of the remaining *k* variables of a signal. If you do not receive a signal we have located the source of the problem.
Step 2. (Optional but useful for very large *p*): Examine the correlation structure of the reduced set of variables. Remove any variable having a very weak correlation (0.3 or less) with all the other variables. The contribution of a variable that falls in this category is measured by the
T_i^2 component.

Step 3. If a signal remains in the sub vector of *k* variables not deleted, compute all $T_{i.j}^2$ terms. Remove from the study all pairs of variables, (X_i, X_j), that have a significant $T_{i.j}^2$ term. This indicates that something is wrong with the bivariate relationship. When this occurs it will further reduce the set of variables under consideration. Examine all removed variables for the cause of the signal. Compute the T^2 terms for the remaining sub vector. If no signal is present, the source of the problem is with the bivariate relationships and those variables that were out of individual control.
Step 4. If the sub vector of the remaining variables still contains a signal, compute all T^2 terms. Remove any triple, (X_i, X_j, X_k), of variables that show significant results and check the remaining sub vector for a signal.

Step 5. Continue computing the higher order terms in this fashion until there are no variables left in the reduced set. The worst case situation is that all unique terms will have to be computed[9].

Case study

Introduction:
The valves are the means for regulating or turning on or off the fluids, which they are put on their direction. the valves which are used in gas transportation, according to their each one usage are made from P.V.C, cast iron, brazen materials.
The vales are classified according to different standards which their most wide spread is the base of the maximum pressure that the valves parts, especially the body and other parts which can tolerate. The valves have developed for different liquids and in different environments in which they must work because of the diversity and variation in different systems, and each one of them are designed for special purposes. Some of these valves have the ability of controlling the current in the valvular form, and some others can prevent the passing current and other group are worked in corrosive systems, and passing the high pressure fluids.

The needle valve
They are a kind of industrial valves in which a needle like part is moved by the designed Screw thread on it and they control the current fluid. This kind of the valves are installed in the passages which are planned to control the current level of fluids. The advantages of using the needle valves are following:
1- too exact set-out of fluid current, especially, gas fluids which can point to the revised gas line from regulators.
2- The ability of using the up more than 3000-6000 psi pressures.
3- The ability of tolerating the high temperatures, because of using the prep roof insulations.

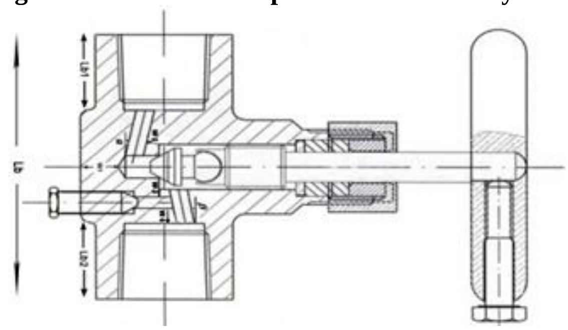
production process of the needle valves
The process of producing the needle valves have eight basic phases. These phases are following respectively, machining, assembling the semi-produced parts, polishing, electroplating, the final assembling, testing and packing, that in this production unit the parts machining phase is done by the auto-cutting set for 6 parts such as body, stem, bonnet, packing, nut, handle. According to the importance of this part of producing, the multivariable controlling is centered on this section.

The multivariable process control steps
First step: (studying the process): Reducing the number of the damaged parts play an important role in the finished price of the produced valve. In view of the sensitivity of the used in gas industry, the least damage or defect in the produced part cause it to be get out completely. After studying the production process, it was specified that the highest junking rate in machining process is related to the body part. And in order to control the statistic process in the first step, it is needed to identify the effective variables in each considered part. The variables which are Measured in producing the body part of the needle valve are as following:

1- The length of the valve body (lb) which is measured on mm.
2- The length of the female NPT entrance port (lb_1).
3- The length of the female NPT outlet port (lb_2)
4- The distance of needle seat until the button bed (w_1)
5- The angle of the entrance port until horizon (α)
6- The distance between the entrance port until the tube of the handle (w_2)
7- The distance from the beginning of the outlet port until the discharge screw (w_3)
8- The distance from the discharge screw until the end of the outlet port (w_4)
9- The angle of the outlet port until horizon (β)

The figure -1 shows the related map to a needle valve by 9 studied variables.

Figure 1. the related map to a needle valve by 9 studied variables.



Likewise, it is specified in figure 1, every change in the measurements of every studied variables results to make changes directly or indirectly in the specifications of the other variables. Thus controlling every variables separately can't be useful, and in view of the Subjects in the previous chapters, the multivariable control is necessary.

Second step: (breaking the process): According to the done studies, it doesn't need to break more the under process.

Third step: In view of the mentioned concept in the first step, it is clear that the number of viable(s) is equal to 9. It is necessary to note that α, β variables are angle and in order to turn these angles to the length from tangent, each angles is used as follow:

$$tg(\alpha) = \frac{b}{a} \quad \Rightarrow \quad b = a.tg(\alpha)$$

$$tg(\beta) = \frac{d}{c} \quad \Rightarrow \quad d = c.tg(\beta)$$

Where b, d are opposite side, respectively, and a, c, are considered the 1 cm distance from the corner angle respectively. The next step is the estimation of the coefficient matrix between these variables. For this purpose, go observation numbers from a daily production line were gathered and the coefficient between them, were calculated, which the results are shown in table (1). As you see, between all the variable is established a too much strong coefficient. Therefore, we can conclude that the situations for using the multi-control methods are very suitable.

Table 1. the coefficient between the process variables.

coefficient	Lb	Lb_1	Lb_2	W_1	W_2	W_3	W_4	α	β
Lb	1								
Lb_1	0.62	1							
Lb_2	0.47	0.25	1						
W_1	0.22	0.24	0.14	1					
W_2	0.52	0.36	0.39	0.15	1				
W_3	-0.74	-0.42	-0.64	0.37	0.18	1			
W_4	-0.35	0.54	-0.42	0.55	0.382	0.76	1		
α	0.45	0.24	0.34	0.31	0.438	0.11	0.27	1	
β	0.61	0.31	0.24	0.27	0.341	0.15	0.23	0.36	1

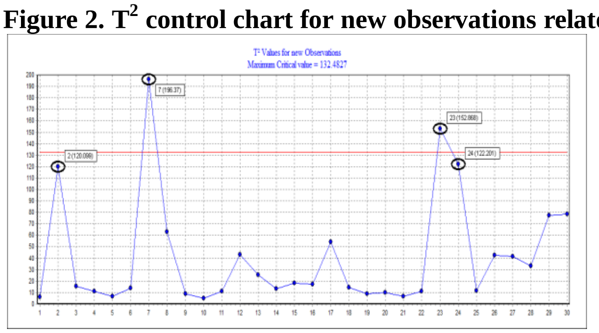
Fourth step: When we are studying the much more numbers of related variables, usually the covariance matrix related to these variables is change into a singular matrix and finding the inverse matrix is not possible, that in these cases, we can use the T_A^2 and SPE statistic simultaneously. But in this case haven't observed any problem.

Fifth step: First of all, a set of including 60 related observations about one day period of functioning of a production line were gathered, and the outlier[3] and missing data were omitted or estimated. Then by using the SAS software, the normal multivariable test were done on the data, and according to the obtained results, there weren't any reason to reject the normal multivariable hypothesis. After that, by using the Qualstat software, Q_i statistic for every observation was calculated and compared with upper control limits base on the β distribution at $\alpha = 0.01$ level. After omitting the sign observations and redrawing the control chart, a set of 54 under-controlled observations were obtained which were considered as reference sample and according to the this sample, the mean and covariance matrix were estimated.

Sixth step: At the end of production line, every 36 valves were packed in each box, and then they were put in the workshop were arranged in cubic form. for gathering sample size 30 we used the cluster sampling method. by this method, at first 3 numbers were selected randomly, and each one of these numbers have shown the number of length, wide, and height in cube orderly. After finding the considered box, from each box, two valves were selected randomly. after 15 times repetitions of this process a sample size of 30 was obtained. It must be noted that, in order to calculate Q_i statistic for new observations in second phase, the mean vector and covariance matrix were estimated by suing the reference sample in first phase. usually α was considered as equal to 0.05.
And by using the Qualstat software, the T^2 control chart was drawn for this observations. The figure (2) shows this chart.
According to the figure (2), the 7th and 23th observations at the α=0.05 level are out-of-control. Moreover, According to the nearness of 2th and 24th observation to the upper control limit , it is specified that these observations will be out of control in the higher significant level. Then for identifying the cause of deviation variables in these 4 observations, we are used the T^2 MYT decomposition method.
According to lots of number of variables, the Qualstat output for decomposition part will be too long which we avoid to bring them in this section, and we considered the results MYT algorithm.

Detecting the cause of deviation in the out of control variables by using MYT algorithm
At the $\alpha = 0.01$ level, we have following:
1- The variable of the body length (lb) is the cause of deviation in 2th observation.
2- The variable of the body length (lb) and the angle of the outlet port until horizon (β), mutually are cause of deviation in 24th observation.
At the $\alpha = 0.05$ level, we have following:
1- The variable of the body length (lb), The angle of the entrance port until horizon (α) and the angle of the outlet port until horizon (β) , mutually are cause of deviation in 7th observation.
The variable of the body length (lb) and the angle of the outlet port until horizon (β), mutually are cause of deviation in 23th observation.
Then in view of identifying the cause of deviation variables and in order to present suitable technique about resolving this problem, we need to study the process more carefully.

Figure 2. T^2 control chart for new observations related to the second phase.



Introducing techniques in order to improve the out of control variables.
Improving the body length (lb)

According to last section, the body length is one of the variables that has enormous effect on the size of the other variables, then being careful in the size of cutting the body of valve is very important, and for decreasing the amount of defective parts during the cutting process, it is necessary to use from the machines which have the neutral limitation or in the other word it has lower natural tolerance. For this reason the technical specifications about existing saws which are in the shops are gathered.

At first, the technical studies are done of different saw models, and then from the saws which are suitable technically, the economical study is done in order to change the wobbling saw that it was found that the BMS 230 DG is the most economical model. The natural tolerance of this saw is located in the technical control limit as follow:

$$PCR = \frac{1.25}{0.54} = 2.315$$

And the natural tolerance is covered by the technical control limit, that it shows, the defective parts are not produced by the saw.

Improving the variable angle of the outlet port until horizon (β)

A part from the body length, two other variables, such angle of the entrance port until horizon (α) and the angle of the outlet port until horizon (β) are shared in the deviation of observations. Then after study on these two variables, it was found that drilling and cutting diagonally (by angle) has a high error in precise cutting and in some cases causes the drill to be broken during the work. The figure 3(left) shows the produced needle valves. In this figure the angles of outlet and entrance tubes are specified carefully.

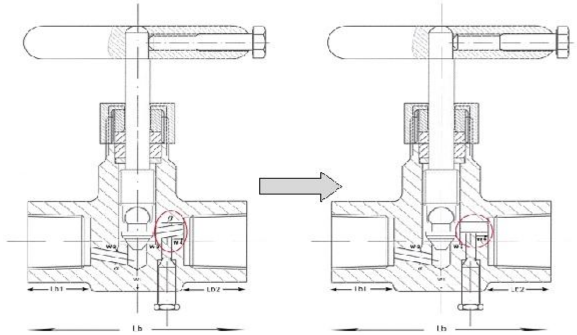
In the other hand, according to the existing standards and sensitivities in gas industries, we can't put the outlet and entrance tube in the one direction, then after doing technical studies, one it was make a decision to stay the entrance tube α angle in the same previous case and it stays in about 8 degree, but the outlet tube to stay in horizon and without considering any angle.

The figure 3(right) shows this changes, as it is clear from this figure the outlet tube is flat and without any angle. Then some samples from the suggested plan according to the figure 3(right), was designed and made, and then after doing the pressure test, temperature test, and confirming the valve performance in this situations and getting necessary certifications, its most production is started.

Conclusion

In this article the multivariable control is used practically in a production unit. For this purpose the line of producing the needle valves in gas industry is considered. As you observed the considered variables have correlation and using the univariate methods in this kind of problems can not be a good solution. After establishing the reference data and estimating the parameters, we construct the T^2 control chart for new observations from the process and out-of-control observations was specified, then by using the MYT algorithm, the cause of deviation variables in these observations were recognized. Then by studying the process, the reasons of deviation were recognized. finally some techniques are introduced for improving the process in two parts, which include the improvements in work tools and some improvements in the valve technical structure that this subject is shown the necessary usage of multivariable control in this industry. It is obvious that by spending more time and using the necessary tools, continues control and spending more investigation costs in achieving the better results and improving the quality of the process is not out of achievement.

Figure 3. the needle valve before and after improving the angle of outlet port



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