Studies on robotic testing equipment used in mechatronic devices manufacturing processes to improve the root cause analysis

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Abstract. In the newest technology of Industry 4.0 and more complex products manufactured, as the innovation requires new flexible manufacturing equipment using robots and complex designed workstations, and the robotic testing equipment as well, the engineers are faced with new challenges to the processing of the information, multiple parameters being collected. The paper aim is to present the studies performed on robotic testing equipment from a manufacturing line of an automotive mechatronic device by using the design of experiments to optimize the 3D movements of the arm, the speed and approach procedure of the testing device. The ANOVA will support the analysis of the repeatability of the movements and find the main factors which lead to variation in measurements, therefore could support the root cause analysis of issues occurred.

1 Introduction

As Mr. Noriaki Kano introduced 30 years ago the principle of the attractive quality, in the model named as his name (Kano's model) when he spoke about different classes of quality [1] expected by the customers, this is the leading factor in customer satisfaction.

Lars Witell et al. wrote in the paper that the classes are: *attractive quality*, *one-dimensional quality*, *must-be quality*, *indifferent quality* and *reverse quality* [2], so the products in the automotive industry start more and more to follow the desired attractive quality to reach and maintain the customer satisfaction.

In Figure 1 is presented how the *attractive quality* is transposed day by day in *one-dimensional quality*, afterward in *must-be quality*, therefore the OEMs and their suppliers are challenged to manufacture most complex products, but with the competitive price.

One of the solutions used often to manufacture and to test these products is the robot arm, which is present today in many fields of the automotive industry. The advantages of using robotic arms are coming mainly from the possibility to do the repetitive tasks, faster, and very accurate. Once that the equipment was attached and set up to the robot arm and the motion was designed and programmed, the device will reproduce the motion paths with a certain variation.

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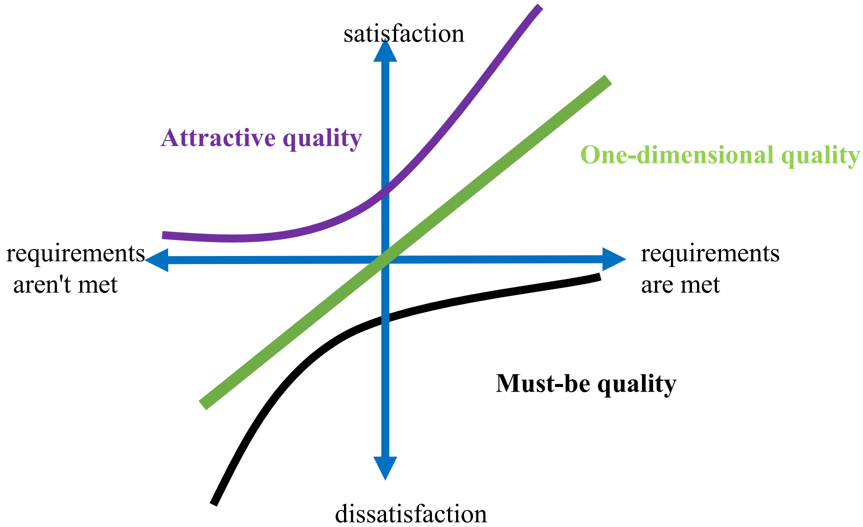

Fig. 1. Kano's model.

The aim of this paper is to perform the studies in order to find the pattern of this small variation and to improve the first part yield in production and to reduce the scrap rate through a better analysis of the root causes.

2 Case study in manufacturing of mechatronic devices

The case study refers to a measuring device that uses the robotic arm to measure the haptic requirements for some switches assembled on a mechatronic device. A switch consists of an assembly of some plastic parts in a housing and a metallic spring, which give the main elastic force of the switch (Figure 2).

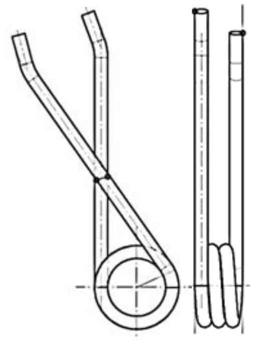

Fig. 2. Spring used in the switch assembly.

The customer requirements for the haptic feeling are transposed in the specification by measuring the front-rear forces (N – Newton), also the travel way (MM – millimetres), the curve of travel way versus forces being as in Figure 3, the main forces (F) and travel ways (S) required by the customer being F1, F1/F2 (represents the haptic feeling), S1 and S2.

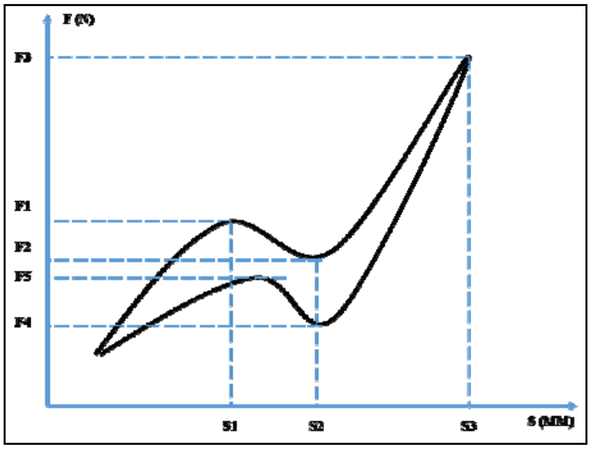

Fig. 3. Force and travel way curve.

The robotic arm is equipped with a dynamometer EDM20 050EL and magnetic sensors to reach the travel start-end, in order to measure within the expected range. The motions of the robotic arm are programmed to reach the same point of pushing-pulling of the switches; the device with the switches is fixed on a rotating table that is moved 90 degrees for each new measurement, so the pushing-pulling point will have some very small variation (one of the factors, which was in analysis for the study)[3].

At the beginning of the study, the batch of the spring was investigated, and the force was measured for a relevant sample, the result shows almost no variation of this characteristic. The measurements done over 25 sampling parts show the curves with a small variation as the way, but not for the force (Figure 4). In the same way, the other plastic components have been studied base on the statistical data out of the ERP implemented, and the characteristics measured over time show a good capability and stability, therefore the variation of the plastic parts was also eliminated from this step of the study.

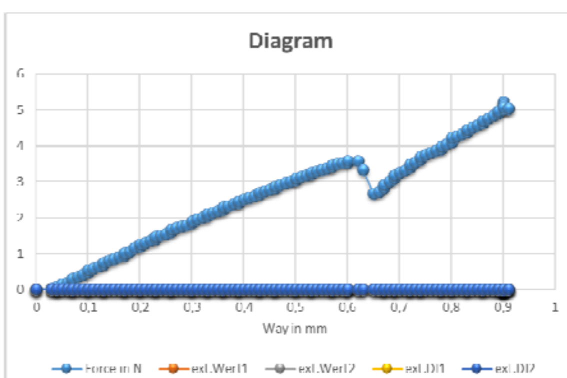

Fig. 4. Force and travel way curve of a spring.

In addition, the measurement device was investigated and a MSA study was performed in order to see the capability of the measurements. The MSA type 1 Gage study performed according to VDA5 booklet consists in measuring 25 times a reference, and the characteristics were force and travel way.

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As the result shows the equipment working well, the next step was to study the measurements from a certain period and to find the patterns or trends that can lead to a direction in the factors' analysis. Therefore, the first part yield (FPY) and scrap rate were monitored for 20 days and the graph shows a big variation (Figure 5).

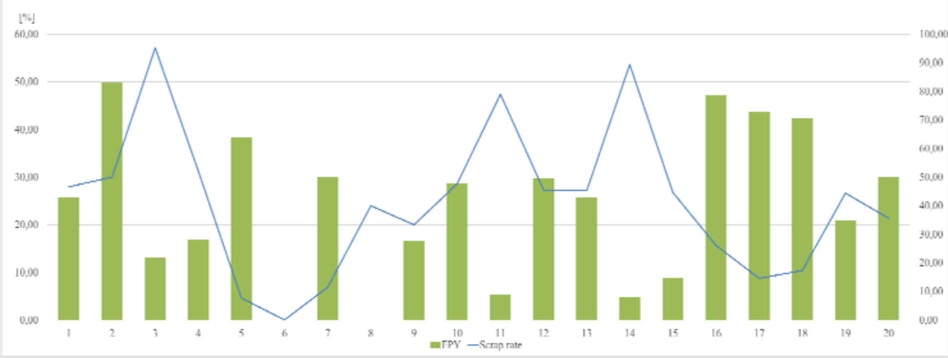

Fig. 5. Variation of FPY and scrap rate.

The motions of the robotic arm start to be adjusted gradually and the experiments run as the following: a number of 2 x 8 groups, each one with 125 parts have been measured for each switch from left and right. As the mechatronic device consists in two pairs of switches placed as in Figure 6, each motion consists in a measurement of the front moving and a measurement of the rear moving, and then the rotating plate will move 90 degrees with the next part, afterward, the robotic arm starts a new cycle. Each switch from left and right is measured with a dedicated robotic arm.

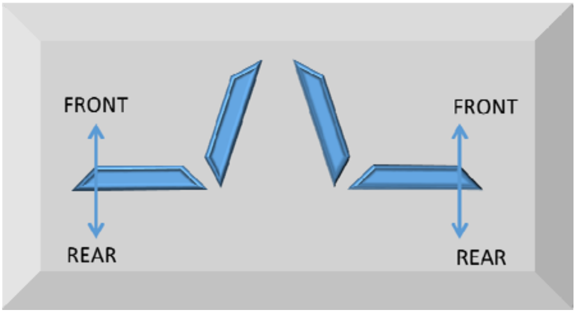

Fig. 6. The switches placed on the mechatronic device.

The data collected by the machine computer consists in all parameters such as forces (F1, F2, F3 etc.) and ways (S1, S2, etc.), and these measured values are available for each button at each end.

As there are too many observations to be processed, the characteristics chose to be used for the further steps, the analysis of variance (ANOVA), was F1 FRONT for the buttons left and right. As a result, by using Minitab software, the factors of the experiments are shown in Table 1.

Table 1. Factor Information.

Factor	Levels	Values
Force	16	F1-1L; F1-2L; F1-3L; F1-4L; F1-5L; F1-6L; F1-7L; F1-8L; F1-1R; F1-2R; F1-3R;F1-4R; F1-5R; F1-6R; F1-7R; F1-8R

The ANOVA one-way method was chosen for the analysis of variance and we begin with the comparison of the means of the groups, so the factor information can be seen in Table 2, also the interval plot with 95% confidence interval in Figure 7.

Table 2. Factor Information.

Factor	N	Mean	StDev	95% CI	Factor	N	Mean	StDev	95% CI
F1-1L	125	6,9757	0,2248	(6,9314; 7,0200)	F1-1R	125	6,8468	0,2676	(6,8025; 6,8910)
F1-2L	125	7,0805	0,3227	(7,0362; 7,1248)	F1-2R	125	6,9373	0,2342	(6,8930; 6,9816)
F1-3L	125	6,9734	0,2722	(6,9291; 7,0177)	F1-3R	125	6,9465	0,2192	(6,9022; 6,9908)
F1-4L	125	7,0319	0,2619	(6,9876; 7,0762)	F1-4R	125	6,8519	0,2335	(6,8076; 6,8962)
F1-5L	125	6,9626	0,2583	(6,9183; 7,0069)	F1-5R	125	6,8151	0,2337	(6,7708; 6,8594)
F1-6L	125	6,9664	0,2219	(6,9221; 7,0106)	F1-6R	125	6,8219	0,228	(6,7776; 6,8662)
F1-7L	125	7,0682	0,2708	(7,0239; 7,1125)	F1-7R	125	6,9172	0,2529	(6,8730; 6,9615)
F1-8L	125	6,9955	0,2718	(6,9512; 7,0398)	F1-8R	125	6,8823	0,2443	(6,8380; 6,9265)

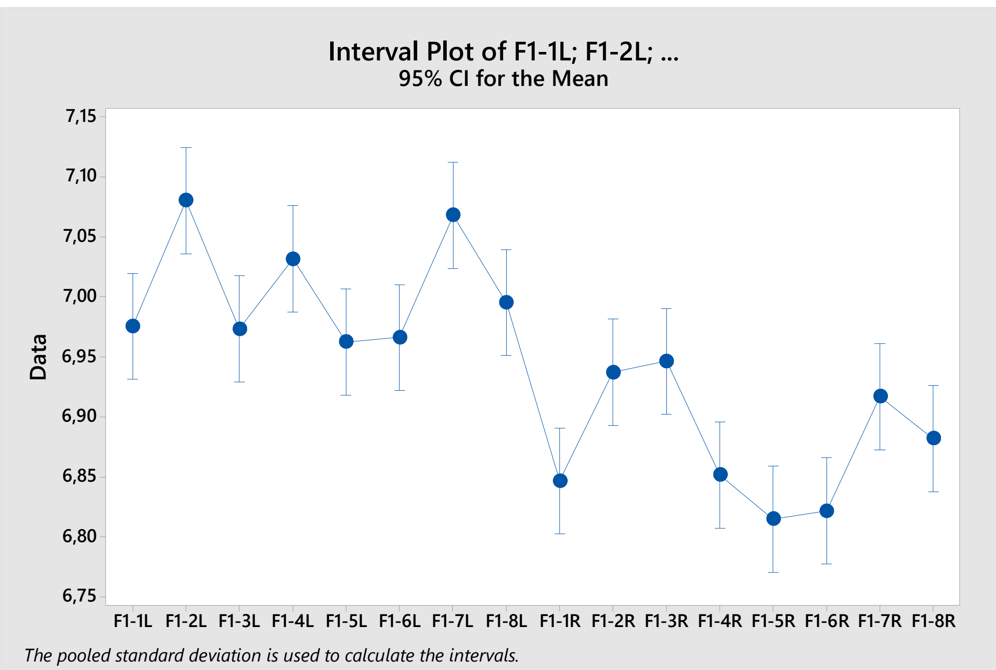

Fig. 7. Interval plot of F1-1L to F1-8R.

From the interval plot can be observed that the measurements of the second robotic arm used for measuring of the right switches are slide down, therefore an adjustment of the motion it will be implemented (as mentioned before, the analysis of the main contributor to the force was performed, so the variation stands for the measurement device).

The ANOVA method evaluates the relative size of variance among group means (between-group variance) compared to the average variance within groups (within-group variance).

And from Table 3 can be seen that the P-Value is low, also the F-Value is greater than F critical, as a result the null hypothesis is rejected, it means that among the means of the groups there is a statistically significant difference at the $\alpha = 0.05$ [5].

Table 3. Analysis of variance.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	15	12,64	0,84268	13,22	0,000
Error	1984	126,46	0,06374		
Total	1999	139,10			

Further steps are to be considered in ANOVA one-way by grouping information using the Tukey method and 95% confidence show the result in Table 4.

It can be seen, as means that do not share a letter are significantly different, therefore the experiments F1-2L, F1-5R, F1-6R are to be considered as significantly different.

Table 4. Tukey Pairwise Comparisons.

Factor	N	Mean	Grouping						
F1-2L	125	7,0805	A						
F1-7L	125	7,0682	A	B					
F1-4L	125	7,0319	A	B	C				
F1-8L	125	6,9955	A	B	C	D			
F1-1L	125	6,9757	A	B	C	D	E		
F1-3L	125	6,9734	A	B	C	D	E		
F1-6L	125	6,9664		B	C	D	E		
F1-5L	125	6,9626		B	C	D	E		
F1-3R	125	6,9465			C	D	E	F	
F1-2R	125	6,9373			C	D	E	F	
F1-7R	125	6,9172				D	E	F	G
F1-8R	125	6,8823					E	F	G
F1-4R	125	6,8519						F	G
F1-1R	125	6,8468						F	G
F1-6R	125	6,8219							G
F1-5R	125	6,8151							G

Similarly, by using the grouping information using the Fisher LSD method and 95% confidence, it can be seen that the experiment F1- 7L is significantly different as mean too.

Table 5. Fisher Pairwise Comparisons.

Factor	N	Mean	Grouping						
F1-2L	125	7,0805	A						
F1-7L	125	7,0682	A						
F1-4L	125	7,0319	A	B					
F1-8L	125	6,9955		B	C				
F1-1L	125	6,9757		B	C	D			
F1-3L	125	6,9734		B	C	D			
F1-6L	125	6,9664			C	D			

F1-5L	125	6,9626			C	D			
F1-3R	125	6,9465			C	D			
F1-2R	125	6,9373			C	D	E		
F1-7R	125	6,9172				D	E		
F1-8R	125	6,8823					E	F	
F1-4R	125	6,8519						F	G
F1-1R	125	6,8468						F	G
F1-6R	125	6,8219						F	G
F1-5R	125	6,8151							G

Finally, based on the Fisher and Tukey tests, the experiment F1-3L it is one of those which shared more letters with the other group.

This experiment shows to be a good candidate for a capability test, in order to see if the process capability reaches the customer expectation.

The capability study performed in comparison with the other two experiments, F1-1L and F1-2L, is presented in Figure 8.

In addition, this is proving that the adjustment from the experiment No. 3, at least for the left robotic arm (before was observed that the right robotic arm need an adjustment to slide up the measurements), is to be implemented then to track again the first part yield and the scrap rate evolution.

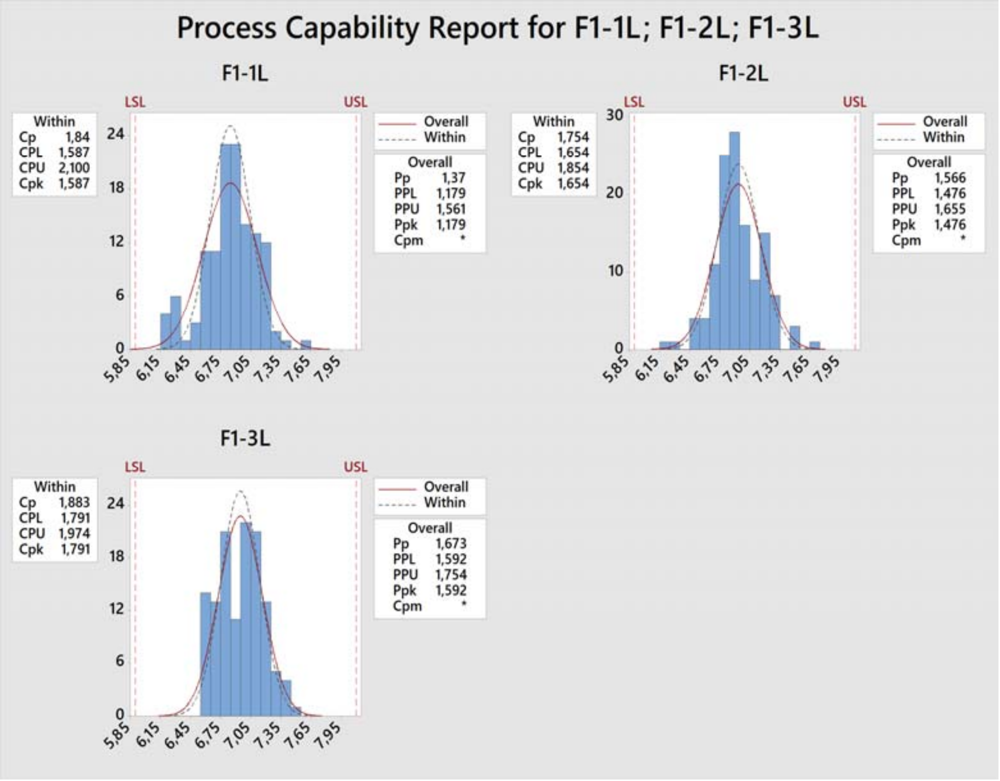

Fig. 8. Process capability of the F1-3L versus F1-1L and F1-2L.

3 Conclusion

This study was generated by the need to improve the processes of manufacturing the mechatronic device and using the robotic arm for measurements of the parameters.

Based on the analysis of variance, was found the adjustment of the robotic arm motion that supports the process to improve the first part yield and to reduce the scrap rate. As the data collected is so large, only a part of it was used to perform the analysis and to conclude the results.

It can be stated, the strength of this study is that the outputs led to the positive result in the manufacturing field.

On the other hand, is a huge opportunity to study the correlation between the parameters measured by these robotic arms and to do the analysis of the variation in order to detect what is the main influence of the single parts variation in the final product variation.

Further steps will follow, and deep analysis will be performed using the optimization of the motions for the robotic arms, also the studying of the part variation influence on the measured characteristic, with the final goal to reduce at the minimum the scrap rate and to increase the first part yield.

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