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On Phase-I of Statistical Control of Thermoforming Process of Decorative Parts of an Automobile Approaching Profile

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Abstract- When a process is controlled statistically approaching profile monitoring, it really addresses practitioners are not concerned traditionally with measurement on a single quality specification or a vector of quality specification. In many real cases it is possible to model a process performance by a functional relationship. This advanced approach of statistical process control is referred to as profile monitoring. Really profile monitoring is referred to as summarizing the quality of a process/ product by a functional relationship. This paper investigates the phase-I of statistical process control for the "thermoforming process" of fender (splash guard) of an automobile manufacturing n Iran named Samand using profile approach. This research indicates the parameters of regression provided by phase-I of statistical process control, are capable to make the opportunity to monitor the process in phase II of statistical control effectively.

Keywords: *Profile, statistical control process, thermoforming, phase I of statistical control process, Samand automobile*

I. INTRODUCTION

In the automotive industry, in order to produce many decorative parts and pieces, the "thermoforming processes" should be used. Thermoforming is a secondary forming process that forms the polymeric sheets as well. In a thermoforming process, at first the thermoplastic sheet, as raw material should be heated to some temperature that causes it becomes soft and malleable based on technical guidelines. It should be noted that in the thermoforming process, the temperature should not be increased so much that the polymer melt and flow.

Iran Khodro Samand car's Fender (splash guard) is a decorative segment which is produced through the thermoforming process. The fender piece is composed of three layers consisting of two layers of felt, and a polymer layer. It should be noted that the polymers between layers of felt are combination of PP and PE. Polyethylene (PE) is one of the easiest and cheapest polymers, which is known as the most widely used plastic materials in industry. It is obtained by the polymerization of ethylene and in abbreviation is shown as PE. Polypropylene (PP) is similar to Polyethylene except that there is a methyl group instead of hydrogen in PP at first the polymer segment should be heated to its soft spot and then it should be pressed, and as a result of pressure applied by the punch and the matrix form, the desired shape is achieved. It should be noted that if the piece does not heat enough, based on the pressure and tension on the piece while forming, the possibility of creating a rupture or tear in the piece is high. The production process is shown by a flowchart in Figure 2 schematically. According to the above explanation, heating control, in this process, is very important. Currently, the plant processes studied in this paper, temperature control for existing furnaces is done through PLC. So that for heating the felt sheet, an alarm signal to the operator can be considered as controller of heating time. In fact, the operator through an alarm bell should be notified that the heating stage should be stopped, and the felt sheet should be sent out of the heating oven, and transfer to the pressing stage. The major weakness of above process is to control the heating process, as follows:

1. In this process, it is assumed that all sheets are the same thickness, and thus PLC is a function of the heating time, and the alarm system is also set accordingly. In fact, there are undeniable changes in the thickness of the sheets essentially, and, because the thickness of the sheet has a direct relation with energy absorption, so by changing the thickness, the rate of heat absorbed by several sheets should be different. This important subject has not been considered for controlling of the process.

2. There is radiation of heat in this process, so that the heat is transmitted through the shaft elements to the felt sheets. The numerical value indicated by the PLC screen is referred to as the percentage of energy produced by the elements of the stove. Then increasing or decreasing the rate of energy impacts on absorbing the energy of segment. In this plant, the controlling process does not take into consideration the rate of increase or decrease in energy, and mutual thermal effect on the sheets.

According to the available documents in the quality control unit in this plant, the most major defects lead to non-compliance and waste products, especially after heating and forming processes are as follows:

1. Surface tear of segments after forming
2. Surface rupture of segments after forming
3. Burning after the thermoforming

Although, in order to overcome the weaknesses of the existing control process, the engineers have executed two processes:

1) installing of insulation around the heating stove in order to make uniform heating; 2) standardizing the number of felt sheets which are placed in the oven, but the reports of quality control unit indicate that three above defects are still considerable in the products. However, through investigation of the initial analysis of the reports of recorded defects, the engineers found that these non-compliances might be took place in the thermoforming process.

By the use of a profile approach, this paper proposes a simple linear regression equation for phase I of statistical process control, especially for Samand car's fender which is produced through the thermoforming process. This approach can show whether the production process of Samand car's fender is under control or out of control.

The second section of our paper introduces the profile approach and its importance in statistical process control. Here, the studies reported in the scientific literature are considered relatively comprehensive. In the third section, the methodology of our study will be discussed. How to collect data is discussed in fourth section. Analyzing of the usable profiles obtained in our study could be discussed as detailed in fifth section five. The sixth section examines the parameters of the phase I of profile. The last section also reports the conclusions of the study.

II. PROFILES AND APPLICATIONS

In statistical process control, normally the quality of a process or product is monitored through distribution of a random variable or a vector, which represents several quality specifications are interrelated. In such conditions, the quality specification could be controlled through control chart(s) for single-variable processes or multivariate processes. But, in fact in some real situations, the quality of a process or product can be described by correlation between a response variable and one or more independent variables. The correlation called "Profile" in the literature of statistical quality control. Since the profiles can draw the quality specification of a product more realistic than the previous method, thus in recent years, a number of writers and researchers have mentioned to the profiles as an important and effective application. Kang & Albin (2000) in their report showed that in some cases the calibration process can be monitored well by a linear profile.

In their study, Kang & Albin (2000) showed two examples of the profile application. The first example was a type of Aspartame (a concentrated liquid), or an artificial sweetener. By this example, the functional properties of the Aspartame content which can be dissolved in one liter of water at different temperatures have been studied and monitored. Figure 3 shows the curves obtained for a given process.

Kang & Albin (2000) in the second example have monitored a linear profile for calibration in semiconductor manufacturing industry. In this example, Kang & Albin (2000) showed that the function of a gas flow controller can be described by a linear regression equation as follows.

$$P = P_0 + \left(\frac{Q_{\max} .R\,T\,t}{V} \right) X$$

Brill (1998) has used two multivariate control charts to control the calibration parameters in order to linear calibrate the multilevel ion chromatography. By this regression equation, the measured pressure P is a linear function of X (as a percentage of the maximum flow). Linear regression function (1) should be described as: the slope depends on the type of gas (R), maximum flow (Qmax), chamber volume (V), temperature (T) and time (t); and the intercept depends on the pressure P_0 Before Kang & Albin (2000) proposed their method, the common method for monitoring the performance of the gas controller was separation of controllers at regular intervals and their calibration; but it caused to lay up the machine about 4 hours. In this way, a gas flow controller valued 1500 USD, during 6 or 7 years of its life, the can impose the expenditure of 250,000 USD because of stop production.

Kang & Albin (2000) suggested that separation of controllers and calibration of them is required when the statistical process control indicates the deviations and the reasons. Kang & Albin (2000) suggested a method for optimizing the interval between two consecutive calibrations of gas flow controller.

In literature of profiles, the other authors proposed some practical examples of positive impact on the use of profiles in statistical process control. Neter et al. (1990) presented three examples in which the process is described by a linear profile. Mestek et al. (1994) investigated the stability of linear calibration curves to determine the photometric Fe +3 7 with sulfosalicylic acid 8. Stover has used it in order to determine the stability of response and suitable frequency of calibration. Boeing Airline 10 has proposed a control chart by the use of profiles. By this way, the control for each place only depends on the responses of that place. Therefore, this method can not use data entirely, it doesn't consider their multivariate structure. Figure 4 shows the location chart proposed by Boeing. Here, the response variable is the angle of the upper wing which was measured at 15 locations for 13 wings.

Young et al. (1999) developed the relation between vertical density of boards and different depths as a non-linear profile. The standard sampling method for vertical density could be use of a profile-meter built in laser technology. The different scanned depths and density of them can be measured through this profile-meter. Walker and Wright (2002) have used this sample and proposed a nonparametric method based on additive models in order to compare the curves of the type. Figure 3 shows data from a sample of non-linear profile.

Jin and Shi (1999) also have used wave-profiles to control the tonnage signals in the pressing process. In addition, Jin and Shi (2001) have applied the wave-profiles in order to monitor and control the process errors. They developed samples of their methods in forming and welding processes and etc..

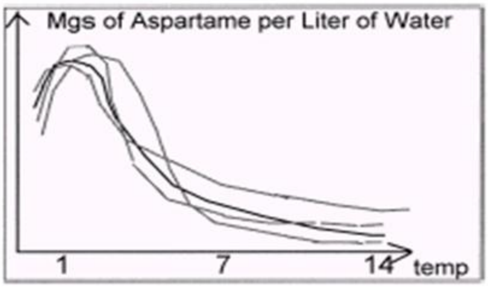

Figure 1. Mg of Aspartame per liter of water in different samples Kang & Albin (2000)

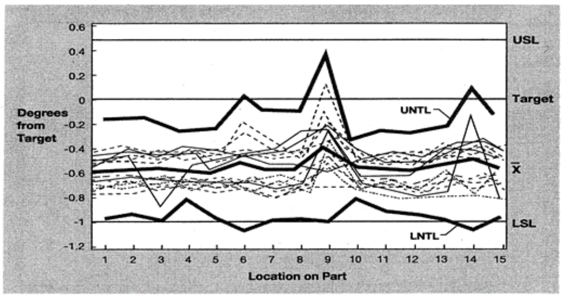

Figure 2. Location Part provided by Boeing (1998)

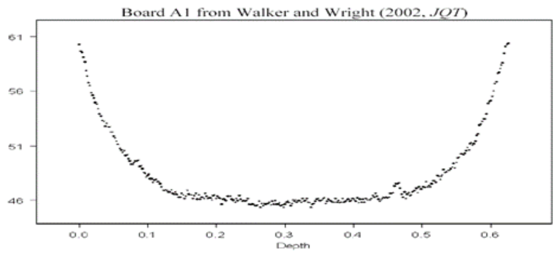

Figure 3. Non-linear profile of vertical density of boards in depth (Walker and Wright (2002)

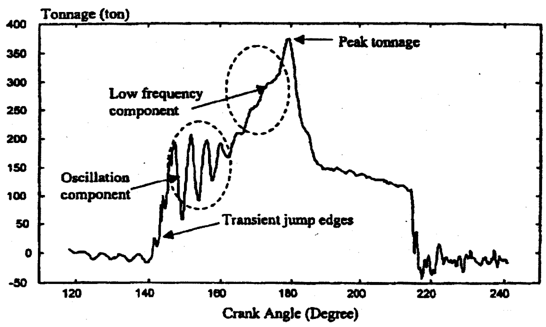

Figure 4. Wave-profile of tonnage signals in the pressing process (Jin and Shi (1999)

As well as a summary of profile applications can be seen in Table 1, in which application and statistical control phase might be mentioned.

TABLE I. SUMMARY OF REPORTS ON THE PROFILE APPLICATIONS

Row	Source	Application	Profile and quality control phase
1	Jin & Shi (1999)	Control of tonnage signals in pressing process	Wave-profiles
2	Kang & Albin (2000)	Control of artificial sweeteners	Simple linear profile, phase I
3	Mahmoud et al. (2007)	Calibration in NASA	Multilevel linear profile, phase I
4	Noorossana et al.(2008)	Calibration of Press 1600 ton	Linear multivariate profiles, phase I and II
5	Saghaee et al. (2010)	Control of lung function of a lung disease	Multinomial profiles, phase I and II
6	Colosimo et al. (2010)	Control of geometric tolerances of a crank	Non-linear profiles Phase I and II
7	Amiri et al. (2010)	The relation between vehicle speed and engine torque	Multinomial profiles Phase I and II
8	Ebadi et al. (2010)	Process capability index for simple linear profiles	Simple linear profiles, phase II
9	Amiri et al. (2011)	The effect of color of shoe on socks with regard to the painting temperature	Simple linear profile, phase I
10	Amiri et al. (2011)	Monitoring of the process ability in simple multivariate linear profiles	Simple multivariate linear profile, phase II
11	Li Xing et al. (2014)	Use the abnormal profiles in the process of coating glass	Abnormal profile, phase I
12	Fokoang wan (2014)	Analysis of process performance for linear correlation between the linear profiles	Simple linear profile, phase II
13	Atashgar et al. (2015)	Monitoring of linear profile Allan variance over the oscillation component and amplifiers	Non-linear profiles, phase II

III. METHODOLOGY

Atashgar [23] has proposed the following steps in order to create a profile:

1- Check the effective variables on a technical specification which shall be used as a response variable. In other words, check that the technical specification is composed of what variables. For simple linear profile, the scatterplot could be used. In addition, at this stage must be careful to choose the variables. In many cases, previous experiences could be effective at this stage. Note that it is not necessary to use all possible variables in order to design an appropriate regression model, but the variables should be adequate.

2- Check that there is a real correlation between independent variables and response variable.

3- Determine the hypotheses (for example, the errors are i.i.d, errors distribution; if there is correlation or not etc.)

4- Check the process and eliminate all the factors which have negative effects on the performance of the natural process or correct them. In other words, at this stage, there shouldn't be observed any unknown factor with abnormal effects on the process, especially according to the physical evidences, and available data.

5- Based on a sampling plan, select n samples of K, and then measure the desirable specifications and record them.

6- Do the "Data Normality Test" for data of above step (5). In step 3 if it is assumed that distribution of data is not normal, do the test for distribution. In case of lack of adequate data, refer to step 4.

7- Estimate the parameters of profile by the use of data from step 5. Now, you have K profiles which have been estimated by n samples.

8- In multivariate regressions, sometimes we have sub-sets of observations with unusual influences. In this case, delete unusual or effective data (For more information, see Atashgar [23].

9- In multivariate profiles, it is expected that there is a correlation between response variable and independent variables, and even among the independent variables. Since this is an intense correlation, it could be applied as a multi-linear case. It can have significant effects on estimations of regression coefficients and model's application. If there is a multi-linear case, estimate the parameters according to this case. (For more information, see Atashgar [23]).

10- Calculate the determination coefficient (to see how to calculate the determination coefficient, refer Atashgar [23]). The determination coefficient makes clear that the estimated model how can well explain the process.

11- Select the appropriate control charts, and calculate the control limits, in order to monitor the estimated parameters of profile to assess the process stability.

12- Check the profile model parameters to be controlled, and then identify the profiles out of control.

13- Delete data of profiles out of control from data of step 4, and then find the reasons, therefore delete deviation factors from the process, and return to step

A. *Data gathering*

To collect data from the thermoforming process of Samand car's fender, the laser thermometer has been used. Laser thermometer or IR thermometers are devices which can measure the surface temperature of objects and display as digital figures. In this study, in order to collect the required data, the temperature of each sheet have been recorded after leaving the heating oven in three points. These three points have been chosen in such a way that cover the entire surface of the sheet in order to measure the temperature of sheet. It should be noted that these three points are the same for all sheets. Also percent of output energy of oven elements could be seen by PLC display. It was considered as the independent variable; and temperature of each sheet was considered as the dependent variable. For profile analysis of data, the percentage energy of stove elements was changed from 65% to 85%, i.e. 5% for each sheet. This analysis method has been considered for 30 samples in three-members group. So there have been created 30 profiles; so the results could be seen in Table 2. Figure 7 shows the scatterplot of samples vs different energies.

TABLE II. TEMPERATURE (C) FOR EACH PROFILES VS % ENERGY

% Of energy	65			70			75			85			85		
Sample No															
1	128	128	128	132	132	133	137	137	139	142	144	143	150	149	147
2	126	126	126	134	133	134	136	139	136	142	142	143	149	149	146
3	126	128	126	133	133	133	137	136	137	143	141	141	148	146	150
4	128	127	128	133	134	132	138	137	139	143	143	142	149	150	148
5	127	127	127	130	134	134	139	139	136	141	142	143	149	145	145
6	127	126	127	130	130	132	136	138	137	143	143	144	149	147	147
7	126	128	128	131	133	131	137	139	138	142	142	144	150	149	145
8	128	126	126	133	131	133	136	137	136	144	142	141	148	145	147
9	127	127	128	133	134	134	136	136	137	141	143	142	148	148	147
10	127	126	127	130	132	130	139	137	139	143	142	144	147	150	147
11	128	128	127	133	133	131	136	138	138	142	142	144	150	148	146
12	128	126	126	130	130	132	139	136	139	144	144	142	149	148	145
13	126	126	127	132	132	130	137	139	139	143	144	142	147	145	148
14	127	128	126	130	131	130	139	138	137	142	141	143	148	145	147
15	128	127	126	130	134	131	137	136	139	141	141	143	150	145	146
16	127	127	128	131	131	132	136	139	137	144	142	142	147	149	146
17	128	128	126	130	133	131	137	137	139	144	144	144	147	149	150
18	127	127	128	134	132	131	137	137	136	142	144	142	148	147	146
19	128	128	127	132	132	134	139	137	138	141	142	144	145	150	146
20	127	126	128	134	134	133	138	136	138	142	144	141	150	148	148
21	126	126	126	132	134	130	136	137	137	141	141	143	149	147	147
22	127	126	127	131	132	131	139	136	138	143	142	144	148	148	146
23	128	126	126	133	132	134	138	138	137	141	143	142	149	150	150
24	126	127	127	134	133	133	136	138	136	143	141	141	148	150	149
25	126	128	128	133	133	133	138	138	139	142	141	143	146	148	147
26	126	128	127	133	132	134	136	137	138	141	143	142	146	147	150
27	128	128	127	133	130	132	139	138	138	142	142	144	150	145	146
28	127	128	126	132	132	131	138	136	138	141	143	142	145	146	146
29	128	126	128	131	131	133	137	138	139	141	142	143	147	149	150
30	128	127	128	133	130	131	136	138	139	141	142	142	146	149	148

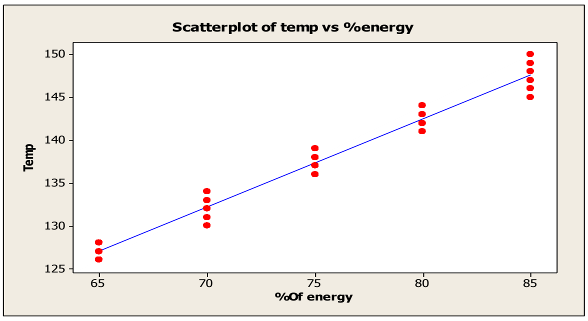

Figure 5. Scatterplot of samples of profile

IV. TERMS OF USING THE LINEAR PROFILES

Momeni [24] has mentioned to terms of using the linear profiles (linear regression)

If:

1-Average errors (expected) are zero.

2-The error variance is constant.

Assumptions 1 and 2 mean that the errors distribution is normal.

3-There is no correlation between the model errors. In other words, $COV\ (e_i, e_j) = 0$

4-The dependent variable has a normal distribution.

Each of these provisions is to establish, now we study.

A. Durbin-Watson Test

Independence of errors (i.e. the difference between real values and estimated values by the regression model) shall be considered when a regression model is used. If the hypothesis of independence of errors is rejected and the errors are correlated together, the regression model cannot be used. Thus Durbin-Watson test shall be used in order to analyze the correlation between the errors.

If the correlation between the errors is shown by p, Durbin-Watson equation will be as follows:

DW=2(1-p)

Its value can be changed between 0 and 4, if it is in the following ranges, the following results can be concluded:

- If p=0, then we have DW=2 and shows that the errors are independent (non- correlation)
- If p=1, then we have DW=0 and shows that the errors have positive correlation
- If p=1, then we have DW=4 and shows that the errors have negative correlation
- If it is in the range of 1.5 to 2.5; non-correlation between the errors will be accepted, unless there is a correlation between the errors.

According to the above scenarios, Durbin-Watson test was calculated for each profile and it can be concluded that the errors assumed be independence, because Durbin-Watson value of all profiles is between 1.5 to 2.5.

$$(1.5 \leq DW \leq 2.5)$$

B. Normality of errors

It is assumed that errors have normal distribution in each profile. In order to check this subject, the normality chart has been used for all profiles, which can be seen in the following figure. The errors are normal.

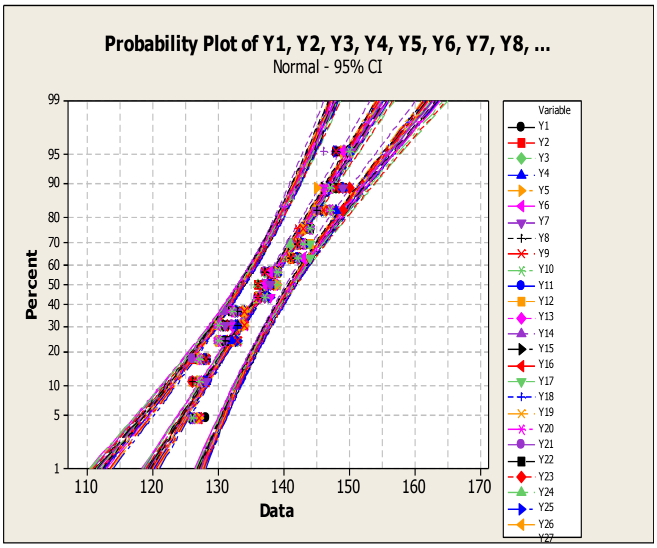

Figure 6. All 30 profiles in 30 charts

V. MONITORING OF PROFILES IN PHASE I

According to simulation studies conducted by Mahmoud and Woodall [6] it was shown that Mahmoud and Woodall's method [6], i.e. the F statistic method, and method of Kim et al. [12] have the performance in detecting shifts in the process parameters Also, if the parameter shifts occur in the middle of Phase I, Mahmoud's method [6] operates better than Kim's [12]. Both methods operate similarly in detecting shifts in the intercept and slope. Therefore, according to Mahmoud's report [6], here we used the F statistic method by Mahmoud and Woodall [6] in order to compare 30 gained profiles.

A. Linearity test

Mahmoud and Woodall [6] suggested that linearity test of "k" regression line is very important before applying the method of phase I. For this purpose, we need to repeat more than one in one or more of the independent variables as well. This test has been shown for the first profile that show proper linear Fit. The test is repeated for all profiles and the results showed proper linear Fit

TABLE III. SHOWS ANALYSIS OF VARIANCE FOR THE FIRST PROFILE

Regression Analysis: Temp 1 versus energy

The regression equation is:

Temp 1 = 59.9 + 1.04 energy

Predictor	Coef	SE Coef	T	P	VIF
Constant	59.933	2.613	22.93	0.000	
Energy	1.04000	0.03469	29.98	0.000	1.000

S = 0.950034 R-Sq = 98.6% R-Sq (adj) = 98.5%

PRESS = 16.0901 R-Sq(pred) = 98.04%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	811.20	811.20	898.77	0.000
Residual Error	13	11.73	0.90		
Lack of Fit	3	1.73	0.58	0.58	0.643
Pure Error	10	10.00	1.00		
Total	14	822.93			

No evidence of lack of fit (P >= 0.1)

B. *Stability of variance*

According to the proposal by Mahmoud woodall [6], to ensure the stability of scattering around the regression line, a control chart could be used.

Mahmoud woodall [6] proposed $F = \frac{MSE_j}{MSE_{-j}}$ (1)

to control variance of values instead of values instead of plotting the values of MSE_j because control limits are constant.

It is shown that $\frac{MSE_j}{MSE_{-j}}$ has F-distribution with n-2 and (k-1) (n-2) degrees of freedom so that n shows the number of samples per profile, and k represents the number of profiles.

It is $MSE_{-j} = \sum_{i \neq j}^{k} \frac{MSE_j}{k-1}$ (2)

Therefore, a Shewhart control chart to monitor process variance σ^2 by the use of MSE_j has high and low control limits.

$$LCL = F_{(n-2),(k-1)(n-2),\frac{\alpha}{2}}$$
$$UCL = F_{(n-2),(k-1)(n-2),(1-\frac{\alpha}{2})} \quad (3)$$

In order to calculate the value of α , in scatterplot control, formulas 4 and 5 by Mahmoud woodall [6] should be used, in this equation the value of K is equal to the number of profiles. Assuming that value of error is $\alpha = 0.05$ thus value of α_2 is equal to 0.0005697.

$$\alpha_1 = 1-(1-\alpha)^{1/3} \quad (4)$$
$$\alpha_2 = 1-(1-\alpha_1)^{1/K}$$

As shown in Figure 7, the variance of samples of thermoforming process is under control.

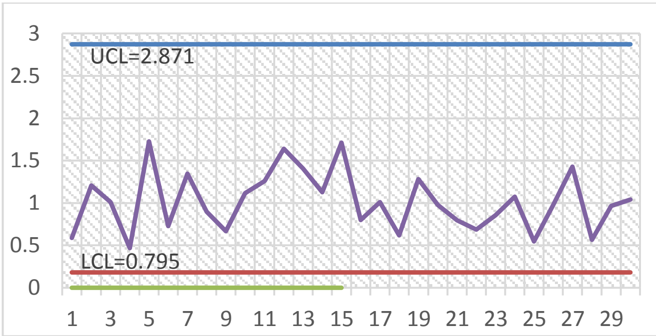

Figure 7. Scattering

C. *Monitoring the process using statistic F*

Mahmoud woodall [6] suggested monitoring of linear profiles in phase I for the comparison of regression lines. In literature of regression analysis, there is a statistical approach based on the use of indicator variables (virtual variables) to compare two or more regression lines in a multiple regression model. Myers [14], Wasserman et al. [10] and Kupper [15] have explained how to use indicator variables for comparison the regression lines. Suppose that there are k bivariate samples and test of regression lines similarity should be conducted for all samples. The first step in technique of indicator variables, suggested by Mahmoud woodall [6], is the integration of k samples in a kn sample; thus k-1 indicator variable could be defined as follows.

If you see i from j sample

$z_{ji} = 1$

Otherwise

$z_{ji} = 0$

$j = 1,2,\dots,k-1$ and $i = 1,2,\dots,kn$

K[th] sample, called a "reference sample". In the next step, the integrated data of multiple regression model is fitted.

$$Y_i = A_0 + A_1 X_i + \beta_{01} z_{1i} + \beta_{02} z_{2i} + \dots + \beta_{0k'} z_{k'i} + \beta_{11} z_{1i} X_i + \beta_{12} z_{2i} X_i + \dots + \beta_{1k'} z_{k'i} X_i + \varepsilon_i$$
$$i = 1,2,\dots,kn \quad (5)$$

In the above equation $k' = k-1$ and ε_i are the iid normal random variables with zero average and variance σ^2. To test the equality of k regression line, the following test will be done.

$$H_0 : \beta_{01} = \beta_{02} = ... = \beta_{0k'} = \beta_{11} = \beta_{12} = ... = \beta_{1k'} = 0$$

H_1 : H_0 incorrect

if H_0 is reduced, so

$$Y_i = A_0 + A_1 X_i + \varepsilon_i \quad (3)$$

The equation for the test H_0 is as follows.

$$F_{test} = \frac{\{SSE\,(reduced) - SSE\,(\text{full})\} / 2(\text{k}-1)}{MSE\,(full)} \quad (6)$$

SSE (full) and SSE (Reduced) are the sum of squares remaining in full and reduced models. Also MSE (full) is the average of error squares for a full model. This equation has an F-distribution with 2 (k-1) and k (n-2) degrees of freedom, if suppose of H_0 is true.

According to calculations, the following values were obtained:

$$2(\text{K}-1) = 58 \;\;,\;\; \text{K}(\text{n}-1) = 420$$

SSE (Reduced) =676

SSE (full) =589.68

F-test value will be equal to:

$$F_{test} = \frac{(676 - 589.68) / 58}{589.68 / (450 - 60)} = 0.9843$$

α_2 for calculation of F when $\alpha = 0.05$; according to Mahmoud Vodal [6] from the formula (9) as follows:

$$\alpha_2 = 1 - (1 - 0.05)^{2/3} = 0.033617$$

Now, according to $F_{0.033617,58,420}$ which is equal to 1.402 ($F_{0.033617,58,420} > F_{test}$) We do not reject the zero value. It can be concluded that the profiles are similar. This means that the phase I of Statistical Quality Control is controlled.

VI. Conclusion

In this research, profile monitoring of the thermoforming process of an automobile manufacturing in Iran was evaluated for phase I of statistical control. Data obtained using thermo laser measurement for 30 samples indicated that in phase I of statistical process control, the profile is under the control statistically. Furthermore the relationship between the value of heat emitted and the amount of heat absorbed is under the control for the sheets over the time and in phase I of statistical quality control. The result anaysis of this research addressed the estimated parameters are capable effectively to provide the functinal approach to control the process in phase-II statistically.

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