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QUALITY IMPROVEMENT OF VEHICLE DRIFT USING STATISTICAL SIX SIGMA TOOLS

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ABSTRACT−Vehicle drift was reduced using statistical six sigma tools. The study was performed through four steps: M (measure), A (analyze), I (improve), and C (control). Step M measured the main factors which were derived from a fishbone diagram. The measurement system capabilities were analyzed and improved before measurement. Step A analyzed critical problems by examining the process capability and control chart derived from the measured values. Step I analyzed the influence of the main factors on vehicle drift using DOE (design of experiment) to derive the CTQ (critical to quality). The tire conicity and toe angle difference proved to be CTQ. This information enabled the manufacturing process related with the CTQ to be improved. The respective toe angle tolerance for the adjustment process was obtained using the Monte Carlo simulation. Step C verified and controlled the improved results through hypothesis testing and Monte Carlo simulation.

KEY WORDS : Robust engineering, Design of experiments, Drift, Monte Carlo simulation, Process capability

NOMENCLATURE

$\bar{x}$: mean of the sample
σ : standard deviation of the sample
v : variance of the sample
H_0 : null hypothesis
H_1 : alternative hypothesis
SST : sum of square of total
SSR : sum of square of regression
SSE : sum of square of error
UCL&LCL : upper & lower control limit
USL&LSL : upper & lower specification limit

1. INTRODUCTION

A six sigma project was suggested for the efficient quality improvement by concentrated CTQ control to get into the world classes by keeping up with world trend of quality engineering. The main boundary of the six sigma project was the statistical process control, the regression analysis using the design of experiments and statistical tolerance design using the Monte Carlo simulation. All of these tools were based upon the statistical analysis. Various six sigma tools were applied for the efficient quality improvement. For example, Brake Judder was improved using DFSS (Design for Six Sigma) and RSM/ Response Surface Method (Kim, 2003) the fishbone diagram was used to generate the factors for process (Hermens, 1997) and service control (Skrabec, 1991). Measurement system capabilities (Repeatability and Reproducibility) were estimated for evaluating measurement error with regards to product variation and specification width in order to guarantee the reliabilities of the experimental results. These results were graphically displayed by James (1991). Design experiments for the optimal design of the shock absorber have been performed. (Lamps, 1993), the design of the suspension (Kim *et al.*, 1996), and the multi-factor analysis of the tire sealing pressure (Chiang *et al.*, 2000). The regression function has been used to represent the relationship between output response and input factors. These studies were mainly performed for multiple response regression analysis (Cho, 2002; Hsieh, 2001), sensitivity analysis of nonlinear models (Sulieman, 2001). Monte Carlo simulation was usually used to obtain the output distribution when the input distributions and transfer function were known. The simulation was the random number procedure to solve the problem that is analytically intractable. The simulation was applied to estimating system reliability (Juan *et al.*, 2002), investigating the variation of a nonlinear transfer function (Hamada, 2001) and the robust design of snap fits (Ching, 2000).

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A great deal of research has been performed on vehicle drift. Vehicle drift is the unintended lateral deviation when a vehicle is driven with steering wheel free. The PRAT (plysteer residual align torque) is tuned by designing the tire fiber angle to cancel the drift tendency of a vehicle. The tire conicity proved to be one of the main factors of drift (Lindenmuth, 1974).

In this paper, the procedure to improve vehicle drift through MAIC (Measure, Analyze, Improve, Control) steps of the six sigma project is described. The values of main factors were measured. The root cause was analyzed through statistical analysis of the measured values. The influence of the main factors on drift were analyzed through a regression function. The toe angle adjustment and tire conicity management process were improved to reduce drift. The respective toe angle tolerance was obtained for the adjustment process using the Monte Carlo simulation based on the toe angle difference tolerance obtained from the regression function. The improved results were statistically verified by a hypothesis test. The process capability and control chart were continued to be drawn for the continuous control of the improved process.)

2. MEASUREMENT

The main factors were obtained in the measurement step through brainstorming using the fishbone diagram of the 6 M category such as the man, machine, material, mother environment, measurement, method as shown in the Figure 1.

Wheel alignment, tire conicity and tire pressure were expected to be main factors. The wheel alignments include the toe, camber and castor angles which are the slopes of the wheel in the plane, front and side view, respectively. The tire conicity is the unbalanced lateral force due to the variation of the manufacturing process. The measurement system capabilities of the main factors were improved before measurement. As for the toe angle, the measurement device was repaired to improve the accuracy and precision. The toe angle measurement variation could be reduced by compensating the steering wheel angle measured by the telemetry system instead of adjusting the steering wheel angle to zero because the steering wheel adjustment is very sensitive due to the clearance in the steering system. The tire conicity measurement variation could be reduced only when a skilled person measured it.

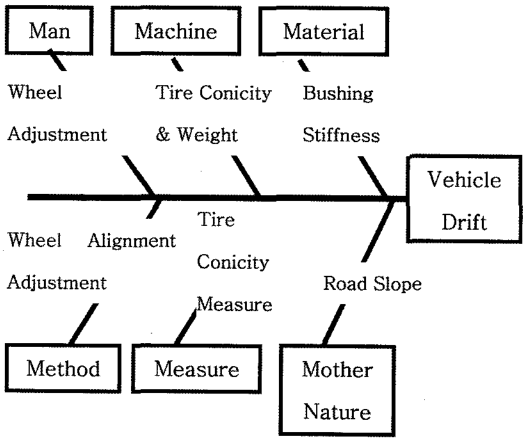

Figure 1. The fishbone diagram to obtain the main factors.

The repeatability of the wheel alignment and tire conicity measurement system were analyzed after the improvement. The reproducibility was not considered because these systems actuated automatically. The wheel alignments and tire conicities of fifteen samples were measured three times to calculate the variations by repetition including the gage installation. The standard deviation of the variation of the measurement repetition was calculated by equation (1).

$$\sigma_r=\bar{R}/d \tag{1}$$

$R = X_{max} - X_{min}$ (for one product)

$$\bar{R}=\sum_{i=1}^{n} R_i/n$$

Where

i : The index of the products

N : The total number of the products

d : The sigma coefficient value obtained from the statistical table referenced by (Mark *et al.*, 1997)

X : The measured values

σ_r : The standard deviation by the variation of the measurement repetition

In order to estimate the repeatability, the P_{tol} and P_{tot} values were calculated. These values are the variation of the measurements relative to the tolerance width and total variation, respectively. They were calculated after the

Table 1. Measurement system analysis results.

	LSL	USL	USL-LSL
Toe angle	−0.09°	0.09°	0.18°
Camber	−0.5°	0.5°	1°
Conicity	50 N	50 N	100 N
	P_{tot}	P_{tol}	results
Toe angle	0.132	0.095	Acceptable
Camber	0.123	0.071	Acceptable
Conicity	0.086	0.143	Acceptable

improvement by equations (2) and (3) referenced by (Mark *et al.*, 1997), as shown in the Table 1.

$$P_{tol} = 6\sigma_r/(USL-LSL) \quad (2)$$

$$P_{tot} = \sigma_r/\sigma_t \quad (3)$$

$$\sigma_t^2=\sigma_p^2+\sigma_r^2$$

σ_r : The standard deviation by measurement variation
σ_p : The standard deviation by product variation
σ_t : The standard deviation by total variation
Criteria : $0.1 \geq P_{tot}, P_{tol}$; *Acceptable*
$0.1 \leq P_{tot}, P_{tol} \leq 3$; *Conditionally Acceptable*
$P_{tot}, P_{tol} \leq 3$; Unacceptable

P_{tot} values of the toe and camber angles were conditionally acceptable, but finally accepted because their process capabilities of the sample cars were good which meant a small σ_p. The P_{tol} value of the tire conicity was conditionally acceptable, but also finally accepted considering the tight tolerance.

Main factors of the vehicle drift were obtained through the fishbone diagram. Measurement system capabilities of the main factors were improved, estimated and ready for the following measuring work in the measurement step.

The tire conicities of 200 tires and the left to right differences of toe angles of 38 vehicles were measured as shown in Table 2 and Table 3, respectively.

Table 2. Left to right tire conicity difference values before improvement. (unit = N)

−13	−10	−13	−18	−34	−9	−28	−11	10	−8
2	8	−6	1	−4	−9	−3	−24	0	17
−23	−11	−4	2	−18	14	−31	11	−27	−28
−21	1	−15	11	−3	−3	−9	13	−7	−9
−1	1	−3	−43	−16	−13	−35	−5	−23	20
−10	12	−18	−7	−8	−8	10	−11	−3	−12
−22	−17	−19	−7	−38	11	−1	4	−6	−12
13	−2	−21	−34	−23	10	−23	2	−2	−22
−19	−11	−20	−6	−17	7	−16	−14	3	−1
−14	−17	−20	−31	−25	−31	−30	0	0	0
−18	−21	−10	−6	−12	6	−3	−8	8	−8
−15	2	−15	−38	0	−18	−12	−16	−37	13
−14	−11	−15	−34	−23	0	−10	−20	−7	−12
4	19	7	−17	0	−13	−15	−9	14	−20
2	−4	−14	−6	−2	7	−6	6	−9	−37
−15	−7	−1	−17	−22	−37	−20	19	−16	−16
−3	27	−6	−12	−6	−9	−8	−11	8	−9
−4	0	−8	−14	7	−10	−7	−9	−7	2
−11	−19	−4	−6	−6	−19	−25	−23	−24	−9
−4	−13	−31	5	5	−18	7	−18	−5	−5

Table 3. Left to right toe angle difference values before the improvement. (unit = °)

0.032	0.026	0.048	0.051	0.038
0.031	0.036	0.03	0.061	0.059
0.056	0.06	0.037	0.028	0.019
0.017	0.026	0.034	0.08	0.075
0.06	0.056	0.044	0.036	0.048
0.036	0.055	0.036	0.066	0.042
0.072	0.049	0.042	0.02	0.033
0.02	0.042	0.018		

Table 4. Process capability of the main factors.

	C_{pk}	C_p
Toe angle	0.33	0.57
Camber angle	1.54	1.72
Tire conicity	0.43	0.47

3. ANALYSIS

Process capabilities of the main factors were obtained by equations (4) and (5) from the measured value(s) in analysis step.

$$C_p = (USL - LSL)/6\sigma \quad (4)$$

$$C_{pk} = \min(USL - \bar{x},\ \bar{x} - LSL)/3\sigma \quad (5)$$

While C_p is the function of the standard deviation only, C_{pk} is the function of the mean and standard deviation. The C_{pk} and C_p are the actual and potential process capability, respectively. The gap between the C_{pk} and C_p is caused by the shift of the mean. It is easier to center the mean than it is to reduce the standard deviation. The gap can be reduced by centering the mean to the target. The process capabilities of the main factors were obtained as shown in the Table 4.

The process capability of the camber angle was considerably good and left little to be improved. The process capabilities of the left to right toe angle difference and tire conicity needed some improvements. Control charts were drawn to analyze the problem.

As for the left to right toe angle difference, the measured values were represented with the control limit

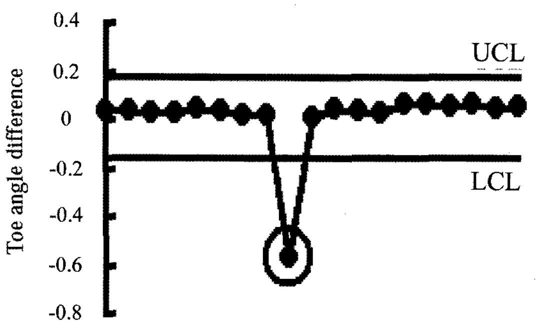

Figure 2. The control chart of the front left to right toe angle difference.

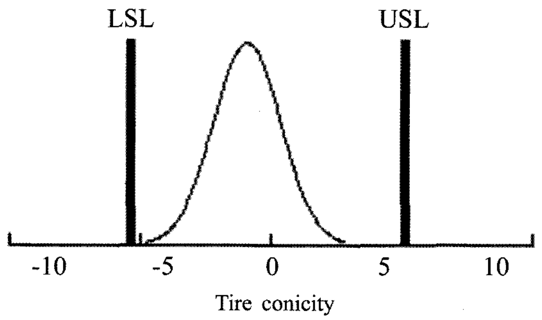

Figure 3. Process capability chart of the tire conicity before improvement.

in the control chart of Figure 2. In the chart, the data were divided into small groups (group size = 2). The standard deviation used to calculate the control limit were obtained by equation (6). This method is similar to the case of measurement system analysis.

$$\sigma = \bar{R}/d \tag{6}$$

$$R = X_{max} - X_{min} \text{ (within each group)}$$

$$\bar{R} = \sum_{j=1}^{n} R_{ji}/m$$

σ : The standard deviation of the group
j : The index of the group
m : The total number of the groups
d : The value obtained from the statistical table referenced by (Mark, 1997)
X : The measured values

The value which is outside of the control limit was given a warning in the chart. This problem seemed to be caused by the imperfect adjustment of the toe angle.

The distribution of the tire conicity was represented with the tolerance limit in the process capability chart of the Figure 3. The bell shaped curve represented the assumed normal distribution of the infinite products with the mean and standard deviation calculated from the measured data. Both the C_{pk} and C_p of the tire conicity were relatively small due to large variations as shown in the chart.

The imperfect adjustment of the toe angle and large variations of tire conicity were considered to be the cause of the poor quality throughout the process capability analysis and control chart in the analysis step.

4. IMPROVEMENT

4.1. Design of Experiments

In order to obtain the influences of the tire conicity and toe angle on the drift with respect to other factors such as the tire pressure and weight distribution, the design of experiments was performed. The half factorial orthogonal array shown in Table 5 was used for the design of experiments. The tire pressure (E) was aliased by the four way interaction (ABCD) of the other factors, so the influence of each could not be determined. The design of experiments started with the assumption that the four way interaction was negligible.

As for the experimental method, the vehicle was accelerated to a speed of 80 km/h with the steering wheel fixed for the first half 100 m. Over the next 100 m, the vehicle speed was maintained at 80 Km/h steady speed with steering wheel free. The lateral deviations were measured by the scale drawn at the end of the 200 m driving distance as shown in Figure 4. Water was poured around the scale to print the tire trajectory. The pass criteria was 100 cm lateral deviation at a vehicle speed of 80 km/h.

A = Rear left to right toe angle difference (unit = °)
B = Front left to right toe angle difference (unit = °)
C = Front left to right tire conicity difference (unit = N)
D = Right weight addition (unit = N)
E = Front left to right tire pressure difference (unit = N/m^2)
Y = Lateral deviation (Output response, unit = m)
※Positive value of output response meant the lateral deviation to the left

The vehicles were driven in the reverse direction. The average values of the two directional experimental results were calculated as shown in Table 5 to cancel the effect of the lateral slope of the road.

The mean and standard deviation of the five repeated experiments were calculated for each of the 16 runs. SSR and SSE were calculated by equations (7) and (8) to estimate the variation by factors and error, respectively.

$$SSR = \sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2 \tag{7}$$

Table 5. Half factorial orthogonal array and experimental results of the drift.

NO.	A	B	C	D	E
1	−0.27	−0.36	−40	0	0
2	−0.27	−0.36	−40	600	4.2 N/m²
3	−0.27	−0.36	40	0	4.2 N/m²
4	−0.27	−0.36	40	600	0
5	−0.27	0.36	−40	0	4.2 N/m²
6	−0.27	0.36	−40	600	0
7	−0.27	0.36	40	0	0
8	−0.27	0.36	40	600	4.2 N/m²
9	0.27	−0.36	−40	0	4.2 N/m²
10	0.27	−0.36	−40	600	0
11	0.27	−0.36	40	0	0
12	0.27	−0.36	40	600	4.2 N/m²
13	0.27	0.36	−40	0	0
14	0.27	0.36	−40	600	4.2 N/m²
15	0.27	0.36	40	0	4.2 N/m²
16	0.27	0.36	40	600	0

NO	1st exp.	2nd exp.	3rd exp.	4th exp.	5th exp.
1	−1.09	−1.05	−1.01	−1.06	−1.01
2	−0.89	−0.80	−0.82	−0.78	−0.74
3	1.29	1.41	1.37	1.33	1.33
4	1.12	1.17	1.33	1.39	1.21
5	−1.23	−1.55	−1.51	−1.60	−1.44
6	−2.02	−1.98	−1.98	−1.96	−1.98
7	0.20	0.23	0.45	0.43	0.34
8	0.53	0.73	0.70	0.64	0.77
9	−2.05	−1.85	−1.95	−1.93	−1.90
10	−2.29	−1.87	−1.95	−2.02	−1.88
11	0.06	0.14	0.29	0.28	0.23
12	0.46	0.35	0.41	0.42	0.40
13	−2.29	−2.32	−2.20	−2.26	−2.39
14	−1.50	−1.35	−1.27	−1.34	−1.30
15	0.40	0.37	0.43	0.45	0.43
16	0.43	0.51	0.48	0.46	0.46

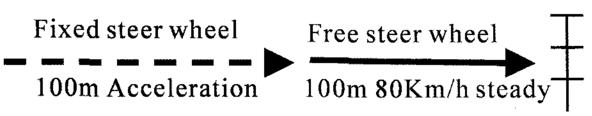

Figure 4. Method of drift experiments.

$$\mathrm{SSE} = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \tag{8}$$

$\hat{y}_i$: The value of y predicted by the regression function (the same for the same run)
$\bar{y}$: Mean of total data
y_i : Value of each data
n : Total number of data (=80 in this study)

The resultant regression function was derived using the Least Square Method so as to minimize SSE. The hypothesis test was performed to determine whether each term could be neglected or not. The hypothesis was built as shown in equation (9).

$$H_0{:}\beta = 0 \quad H_1{:}\beta \neq 0 \tag{9}$$

β : Regression coefficient

The t statistic for each regression coefficient was calculated as shown in equation (10).

$$t = (\beta - 1)(n-2)\sqrt{S_x}/SSE \tag{10}$$

$$S_x = \sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2 / n$$

x_i : The data of independent variable
n : The number of data of independent variable

Finally, the mean of lateral deviation could be represented as a function of the normalized coded variable of factors by equation (11). The regression terms, whose null hypothesis (H_0) were not rejected were neglected in order to represent only the CTQ.

$$Y = (-48.7 - 27.4A - 16.3B + 112.2C + 23.4AB)/100 \tag{11}$$

In order to prove the acceptability of the regression function, the coefficient of determination R^2 and F statistic were introduced to represent the portion of the variation by the regression function relative to the portion by the error. Those values were calculated by equations (12) and (13) to prove the reliability of the regression function.

$$R^2 = SSR/(SSR + SSE) \tag{12}$$

$$F = MSR/MSE \tag{13}$$

※Reliability criterion :
$R^2 > 0.7$ and $F > F_0(k, n-k-1, \alpha)$:
MSR = SSR/k, MSE = SSE/(n−k−1)
k : Number of coded variables (=32 in this study)
n : Number of total data points (=80 in this study)
F_0 : Critical F value obtained from the inverse F distribution
α : Significance level of the probability (set at 0.01 in this study)

Table 6. Factor level value to obtain the toe angle difference tolerance.

Factor		value	condition
Drift	X	1 m	criterion
Rear toe angle diff.	A	–0.67	LSL
Front tire conicity diff.	C	–0.25	LCL
Right weight addition	D	1	Design
Front tire pressure diff.	E	0	Design

The calculated R^2 and F values were 0.996 and 1594.1. These were both larger than the critical values 0.7 and $F_0(32, 47, 0.01) \fallingdotseq 2.1$.

The confirm experiment was also performed to prove the acceptability of the regression analysis. It was performed by setting the right weight addition 600 N and all the remaining code level values to zero which was the design condition of the vehicle. The upper and lower control limit of the 0.74 m and 0.23 m. These values were calculated from the above regression function with the same conditions. The confirmed experimental results of 0.27, –0.42, –0.51, –0.35, –0.46 m were all within the control limit.

The acceptability of the regression function was proven by the R^2, F value and (confirm experiment). The following conclusions were obtained for the vehicle through the observation of the magnitude of the regression coefficients:

(1) The tire conicity was most dominant drift factor.
(2) The largest interaction was between front and rear left to right toe angle differences.

4.2. Toe Angle Tolerance Design

The toe angle was adjusted in the production line although the toe tolerance was specified in the drawings. (The respective toe angle tolerance was obtained concerned with the adjustment process using the Monte Carlo simulation (as/with) the following procedure.)

At first, the front left to right toe angle difference tolerance was obtained through equation (11) because the toe not the toe angle difference was the major factor in the drift. The toe was proportional to the sum of the left and right toe angles. (The toe could be concerned with the tire wear rather than the drift. The drift value and normalized code level values of the factors in equation (11) were set as shown in Table 6.

The front toe angle difference tolerance was obtained as $\pm 0.189^\circ$ with the above values set in the regression function. The standard deviation of the front toe angle difference for the six sigma goal was obtained as $0.189^\circ/6$ ($\fallingdotseq 0.03^\circ$).

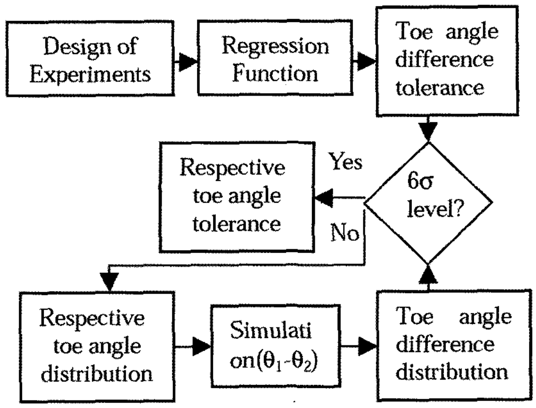

Figure 5. Procedure to obtain the respective toe angle tolerance.

The front respective toe angle tolerance was obtained from the standard deviation of the front left to right toe angle difference using the Monte Carlo simulation. The input and output of the Monte Carlo simulation were the distribution of the left and right respective toe angle and toe angle difference,. The transfer function was naturally defined as the left toe angle subtracted by the right toe angle. Both of the two inputs were assumed to be normally distributed with (a zero mean/a mean of zero).

The input standard deviation was obtained by the trial and error method as 0.022° to get the output standard deviation 0.03° obtained through the previous procedure. In order to obtain the tolerance of the respective toe angle from the standard deviation, environmental factors were considered. These were represented as the shifts of the means by 1.5σ. The tolerance was calculated by the control limit as shown in equation (14).

$$Tolerance = 1.5\sigma + 3\sigma = 4.5\sigma \fallingdotseq 0.1^\circ \quad (14)$$

The rear respective toe angle tolerance was obtained in the same way. The above respective toe angle tolerance design procedure could be explained as shown in the Figure 5.

4.3. Process Modification

As the toe angle and tire conicity proved CTQ through the observation of the regression function, the improvements of toe angle and tire conicity became the main issue.

(1) The toe angle adjustment

The final button of the toe angle adjustment was modified to be actuated only after perfect adjustment.

(2) The tire conicity management

The tire conicity management process was standardized. The variation of the left to right the tire conicity differences was reduced by dividing them into two groups. The reason for grouping tire conicity was to reduce the left to right tire conicity difference in the assembled state. The tires were grouped into two groups: 10~30 N group (group 1) and 30~50 N group (group 2). Tires were selected and assembled within a group. Tires were marked to represent the tire conicity group and direction. Tires were assembled in opposite direction of the conicity to cancel the effect.

The left to right toe angle and tire conicity differences proved CTQ through the statistically verified regression analysis in the improvement step. The toe angle adjusting process and tire conicity managing system were modified to prevent the cause of poor quality found out in the analysis step. The tolerance of the respective toe angle was designed through the Monte Carlo simulation for toe angle adjustment.

5. CONTROL

In order to verify the improvement through statistical tools, left to right toe angle differences of 38 vehicles were measured after the improvement as shown in Table 7.

5.1. Control Chart

In order to monitor the control of the left to right toe angle difference, the control chart was drawn continuously. The data were divided into nineteen groups to calculate the mean of each group. By the central limit theorem the mean was approximately normally distributed. The control limit where 99.7% of the mean of each group was expected to exist, were calculated by equations (15) and (16). The left to right toe angle difference was well controlled within the control limit after the improvements as shown in the control chart of Figure 6.

$$UCL=\bar{x}+3\sigma/\sqrt{n} \quad (15)$$

$$LCL=\bar{x}-3\sigma/\sqrt{n} \quad (16)$$

Table 7. Left to right toe angle difference values after the improvement.

-0.015	0.093	0.067	0.066	0.047
0.038	0.025	0.033	0.058	0.029
0.048	0.032	0.034	0.051	0.022
0.043	0.03	0.038	0.043	0.08
0.059	0.026	0.11	0.027	0.028
0.017	0.067	0.023	0.072	0.043
0.052	0.027	0.032	0.050	0.031
0.016	0.025	0.035		

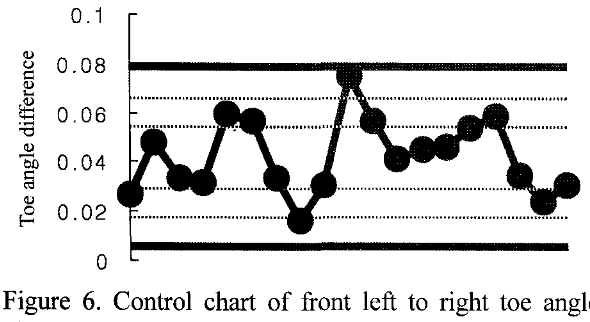

Figure 6. Control chart of front left to right toe angle difference after the improvement.

5.2. Hypothesis Test

The improvement of the left to right toe angle difference distribution was verified by the hypothesis test. (The test were performed on the basis of the t and F distribution for the validation of the significant change of the mean and variance, respectively. The hypothesis to test the significant change of the variance was established as shown in equation (17). The significance level of the probabilities was set at 0.01 to decide whether the null hypothesis should be rejected or not.

$$H_0: V_b \leq V_a \quad H_1: V_b > V_a \quad (17)$$

The F statistic was calculated as shown in equation (18).

$$F = V_b/V_a \quad (18)$$

V_b : Variance before improvement
V_a : Variance after improvement

The DOF (Degree of Freedom) was calculated by equation (19).

$$DOF = n - 1 \quad (19)$$

n : sample size

The hypothesis to test the significant change of mean was established as shown in equation (20).

$$H_0: \bar{x}_a = \bar{x}_b \quad H_1: \bar{x}_a \neq \bar{x}_b \quad (20)$$

The Z test of normal distribution was used because the sample sizes were large enough. The Z statistics for the two samples were calculated by equation (21).

$$Z=(\bar{x}_b-\bar{x}_a)/\sqrt{\sigma_b^2/n_b+\sigma_a^2/n_a} \quad (21)$$

Probabilities for the null hypothesis to be true, were calculated to be 0.358 and 0, respectively, through t and F distributions. There was not enough evidence to reject the null hypothesis about the mean. However, significant change of the variance was (concluded/determined) with 99% confidence.

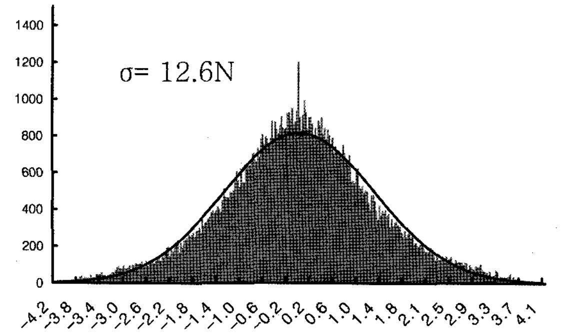

Figure 7. Front tire conicity difference distribution before grouping.

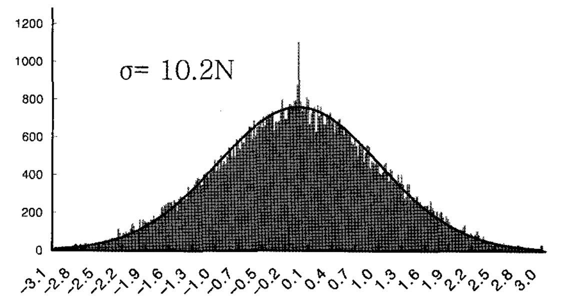

Figure 8-1. Front tire conicity difference distribution after grouping (group 2).

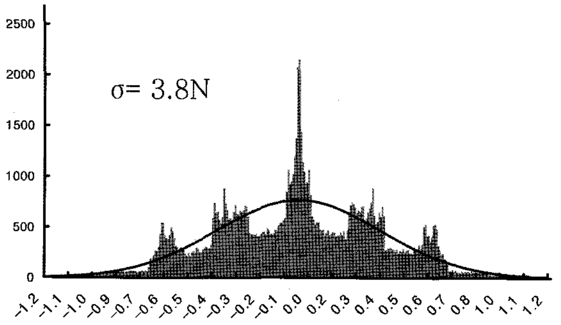

Figure 8-2. Front tire conicity difference distribution after grouping (group 1).

5.3. Tire Conicity Distribution

The distribution of the left to right tire conicity difference could be also calculated using the Monte Carlo simulation. The input and output of the simulation were the distribution of the individual and assembled tire conicity. The transfer function was defined as the left one subtracted by the right one because the tires were assembled in opposite direction of tire conicity. The tire conicities of 200 samples were measured to be prepared for the Monte Carlo simulation. The data were randomly selected and calculated 100,000 times from the sample. The standard deviation of the front tire conicity differences were decreased after grouping as shown in Figures 7 and 8.

The improvement of toe angle adjusting process and tire conicity managing system were verified through statistical tools such as the control chart, hypothesis test and Monte Carlo simulation. They were continued to be utilized for the continuous control of the quality.

6. CONCLUSION

The tire conicity and toe angle difference proved to be the most influential factors on the drift through the observation of the regression function obtained by the design of experiments. The adjusting process and measurement system capabilities of tire conicity and toe angle were improved and standardized. The left to right toe angle difference was controlled in the stable condition by process modification leading the perfect toe angle adjustment. The standard deviation of the tire conicity difference could be reduced by the tire conicity grouping system. Reductions of the left to right toe angle difference and tire conicity were verified by the statistical hypothesis test and Monte Carlo simulation.

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