Using Quality Management Methods in Knowledge-Based Organizations. An Approach to the Application of the Taguchi Method to the Process of Pressing Tappets into Anchors

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Abstract. This paper presents a study on the modelling and optimization of certain variables by using the Taguchi Method with a view to modelling and optimizing the process of pressing tappets into anchors, process conducted in an organization that promotes knowledge-based management. The paper promotes practical concepts of the Taguchi Method and describes the way in which the objective functions are obtained and used during the modelling and optimization of the process of pressing tappets into the anchors.

1. Introduction. An Overview
G. Taguchi proposes a systematic and efficient method to achieve an experiment, leading to an optimum formula in terms of performance and costs. Taguchi’s method uses an orthogonal array which allows division of the experimental plan area and also to select the orthogonal array for experimentation, which facilitates a large number of variables with a small number of experiments.

Experimental determinations are influenced by the variability of environmental conditions - temperature, humidity, dust, etc., by the variability of the characteristics of the raw materials and components used and also by the workers different operating methods [1]. G. Taguchi calls this variability - noise factors [2]; the strategy he uses is not to control these factors (which sometimes can be expensive), but instead to minimize their impact.

In this research paper, the Taguchi’s method will be used to present a study on the modelling and optimization of certain variables of the process of pressing tappets into anchors.

So, after inserting the tappets [3] (ident no 44075) into their anchors (ident no 43983) there are several nonconformities: deformed tappets (concentricity 0.12, higher than 0.12mm) and tappet length, non-compliant level 20.2±0.1 (higher than 20.3mm). This operation is performed by SCHMIDT Press Control 1001, figure 1.

The press is connected to a monitor in which specialized programs are entered for each type of component, with all documentation requirements. For each product the force and the press stroke are introduced in a graph, figure 2.

When the component is changed, the program has to be changed as well but not before saving the previous program. The program displays the graphs of the previous 100 processed components, and
the left panel on the screen displays the quantity of the last order as well as the percentage of defects. The evolution of reuse, expressed in PPM, is presented above in figure 3.

![Figure 1. The SCHMIDT Press Control 1001.](image1)

![Figure 2. The Monitor of the SCHMIDT Press Control 1001.](image2)

Although, in certain weeks, an outage is detected, in all 11 weeks analyzed the evolution of PPM is decreasing; in the last 4 weeks, the level of refuse is around 4%. However, one must optimize the process so that it reaches 0.5%, the level accepted by the customer.

![Figure 3. Internal PPM.](image3)

Nonconformities are presented in figure 4; the most frequent nonconformities are level 20.2+/−0.1 too high and © 0.12 too high, i.e. 80% of all nonconformities.

![Figure 4. Types of defects.](image4)

### 2. The Selection of Features which Require Optimization
In order to be able to choose features that require optimization a brainstorming session was held, with several participants: quality manager, quality analyst, production manager, production-line supervisor, engineer, maintenance technician. Due to the fact that the two major defects, level 20.2+/−0.1 and concentricity value lower than 0.12, cannot be permanently quantified, they are considered qualitative criteria. Qualitative criteria to be monitored:
a) Level 20.2+/−0.1 and concentricity < 0.12;
b) Other defects;
All criteria must be minimized.

The selected factors are shown in the table below, on two levels. Next the Taguchi Method will be used [4, 5, 6, 7].

**Table 1.** Controlled factors and their levels.

| Factor       | Controlled Factor | Level 1   | Level 2     |
|--------------|-------------------|-----------|-------------|
| A            | Hubs              | current   | new         |
| B            | Pressing race     | 0.3kN     | >0.3kN      |
| C            | Tappet lubrication| No lubrication | With lubrication |
| D            | Pressing pressure | 4 bar     | 6.6 bar     |
| E            | Press stroke      | 29.2 mm   | 32.7 mm     |
| F            | Component pairing | random    | set         |

3. Developing experiments and the matrix

For the selected case, there are 64 ($2^6$) trials; an experiment matrix L64 must be developed, which is compatible with the objectives of the chosen experiment, but because of the fact that each level of each factor is combined with which level of the other factors one matrix with 8 trials is enough, of a factorial fractioned plan, in which the first column will include the number of trials, in the last column the calculation of the Ac controlled factors interaction and in the central columns the levels of the controlled factors.

**Table 2.** The factorial fractioned plan for 6 factors on 2 levels.

| Trial No | A | B | C | D | E | F | AC |
|----------|---|---|---|---|---|---|----|
| 1        | 1 | 1 | 1 | 1 | 1 | 1 | 1  |
| 2        | 1 | 2 | 1 | 1 | 2 | 2 | 1  |
| 3        | 1 | 1 | 2 | 2 | 2 | 1 | 2  |
| 4        | 1 | 2 | 2 | 2 | 1 | 1 | 2  |
| 5        | 2 | 1 | 1 | 2 | 2 | 1 | 2  |
| 6        | 2 | 2 | 1 | 2 | 1 | 2 | 2  |
| 7        | 2 | 2 | 1 | 2 | 2 | 1 | 1  |
| 8        | 2 | 2 | 1 | 2 | 1 | 2 | 1  |
For each of the trials nonconformities were sampled every two hours, arranged according to the two groups of criteria which need to be minimized:

a) Level 20.2±/0.1 and concentricity < 0.12;
b) Other defects;

a) The answers for the first criteria (Level 20.2±/0.1 and concentricity < 0.12) are shown in the table 3.

Table 3. Answers for the first analysed criterion.

| Trial no | Interval 1 quantity | Interval 2 quantity | Interval 3 quantity | Interval 4 quantity | Average y | Standard deviation s | S/N dB |
|----------|---------------------|---------------------|---------------------|---------------------|-----------|----------------------|--------|
| 1        | 3                   | 1                   | 2                   | 5                   | 2.75      | 1.48                 | -9.89  |
| 2        | 2                   | 2                   | 5                   | 2                   | 2.75      | 1.30                 | -9.66  |
| 3        | 2                   | 2                   | 1                   | 1                   | 1.50      | 0.50                 | -3.98  |
| 4        | 2                   | 1                   | 1                   | 2                   | 1.50      | 0.50                 | -3.98  |
| 5        | 0                   | 0                   | 1                   | 0                   | 0.25      | 0.40                 | 6.53   |
| 6        | 0                   | 1                   | 0                   | 0                   | 0.25      | 0.40                 | 6.53   |
| 7        | 1                   | 1                   | 2                   | 0                   | 1.00      | 0.71                 | -1.77  |
| 8        | 2                   | 1                   | 3                   | 0                   | 1.50      | 1.12                 | -5.45  |
|          |                     |                     |                     |                     | ≈1.44     |                     | ≈-2.71 |

First the average is calculated for every line, then the standard deviation, according to the formula:

\[ s = \sqrt{\frac{\sum(X - \bar{X})^2}{n}} \]  
(1)

Where:  
s – standard deviation  
X – Individual value;  
\( \bar{X} \) – Average of values;  
n – Number of samples.

The ratio signal/noise is required so that the process might be optimized; in the case of a criterion that needs to be minimized it is obtained according to the formula below:

\[ \frac{S}{N} = -10 \log(s^2 + y^2) (dB) \]  
(2)

b) The answers for the second criterion (other defects) are show in the table 4.

The comparison of the average results for each level, which is equal to the arithmetic mean of the results of the ratio S/N for each trial where the controlled factor is on the same level, such as:

A on level 1 (A1), average result:

\[ A1 = \frac{(-9.89) + (-9.66) + (-3.98) + (-3.98)}{4} = -6.88 \ (dB) \]  
(3)

A on level 2 (A2), average result:

\[ A2 = \frac{6.53 + 6.53 + (-1.77) + (-5.45)}{4} = 1.46 \ (dB) \]  
(4)

Table 4. Answers for the second analysed criterion.

| Trial no | Interval 1 quantity | Interval 2 quantity | Interval 3 quantity | Interval 4 quantity | Average y | Standard deviation s | S/N dB |
|----------|---------------------|---------------------|---------------------|---------------------|-----------|----------------------|--------|
| 1        | 1                   | 1                   | 0                   | 1                   | 0.75      | 0.43                 | 1.26   |
Average results S/N for each factor are displayed in the table 5:

**Table 5.** Average results of the ratio S/N for each of the controlled factors depending on the analysed criterion and level.

| Level 1 | Level 2 | No factors | Level 1 | Level 2 |
|---------|---------|------------|---------|---------|
| -6.88   | 1.46    | A          | 4.10    | 3.55    |
| -2.28   | -3.14   | B          | 4.10    | 3.55    |
| -1.62   | -3.79   | C          | 4.10    | 3.55    |
| -6.69   | 1.27    | D          | 1.58    | 6.07    |
| -3.20   | -2.22   | E          | 3.11    | 4.54    |
| -4.91   | -0.51   | F          | 4.10    | 3.55    |

The comparison of average results for each level is equal to the arithmetic mean of the results of all averages of measured values where the controlled factor was on the same level such as:

A on level 1 (A1), average result:

$$A_1 = \frac{2.75 + 2.75 + 1.50 + 1.50}{4} = 2.13 \text{ (dB)} \quad (5)$$

A on level 2 (A2), average result:

$$A_2 = \frac{0.25 + 0.25 + 1.00 + 1.50}{4} = 0.75 \text{ (dB)} \quad (6)$$

Average results of the values measured for each factors are shown in the table 6.

The average effect, calculated as difference between medium results of each controlled factor on the same level and the total average of answers (T), such as:

$$EA_1 = A_1 - T = (-6.88) - (-2.71) = -4.17 \text{ (dB)} \quad (7)$$

$$A_2 = A_2 - T = 1.46 - (-2.71) = 4.17 \text{ (dB)} \quad (8)$$

**Table 6.** Average results of the measured values for each of the controlled factors depending on the analysed criterion and level.

| Level 1 | Level 2 | No factors | Level 1 | Level 2 |
|---------|---------|------------|---------|---------|
| 2.13    | 0.75    | A          | 0.44    | 0.44    |
| 1.38    | 1.50    | B          | 0.44    | 0.44    |
| 1.50    | 1.38    | C          | 0.44    | 0.44    |
| 2.00    | 0.88    | D          | 0.63    | 0.25    |
| 1.50    | 1.38    | E          | 0.50    | 0.38    |
| 1.69    | 1.19    | F          | 0.44    | 0.44    |
The results of the average effect for each factor and for the first analyzed criterion are shown in the table 7.

**Table 7.** Effects of the first quality criterion.

| EFFECT on the S/N ratio | No factors | EFFECT Measured Value |
|-------------------------|------------|-----------------------|
| Level 1                 | Level 2    |                       |
| -4.17                   | 4.17       | A                     |
| 0.43                    | -0.43      | B                     |
| 1.09                    | -1.08      | C                     |
| -3.98                   | 3.98       | D                     |
| -0.49                   | 0.49       | E                     |
| -2.20                   | 2.20       | F                     |

If the value of the interaction between factors A and C was 0, then the two line would be parallel.

The answer of the relative S/N ratio on the interaction of factor A1C1 for the first criterion is the sum of all answers of S/N ratio when both factors are on level 1 in that case:

$$A1C1 = \left(\frac{(-9.89) + (-9.66)}{2}\right) = -9.78 \text{ (dB)}$$  \hspace{0.5cm} (9)

Calculations are similar for all the other factors. The interaction is calculated considering the general average of S/N answers and the average of all measured values, for the first analyzed criterion:

$$lA1C1 = A1C1 - T - EA1 - EC1 = (-9.78) - (-2.71) - (-4.17) - 1.09 = -3.99 \text{ (dB)}$$  \hspace{0.5cm} (10)

All the calculations for the other factors are similar, and the data is shown in the table 8.

**Table 8.** Interaction effects for the first analysed criterion.

| Interaction | A1C1 | A1C2 | A2C1 | A2C2 |
|-------------|------|------|------|------|
| Effect on the S/N ratio | -3.99 | 3.98 | 3.98 | -3.99 |
| Effect on the measured value | 0.56 | -0.57 | -0.56 | 0.56 |

The results of the average effect for each factor and for the second analyzed criterion are displayed in the table 9.

**Table 9.** Interaction effects for the second analysed quality criterion.

| EFFECT on the S/N ratio | No factors | EFFECT Measured Value |
|-------------------------|------------|-----------------------|
| Level 1                 | Level 2    |                       |
| 0.28                    | -0.27      | A                     |
| 0.28                    | -0.27      | B                     |
| 0.28                    | -0.27      | C                     |
| -2.24                   | 2.25       | D                     |
| -0.71                   | 0.72       | E                     |
| 0.28                    | -0.27      | F                     |

The interaction of the Ac factors depending on the general average of S/N answers and the measured values for the second analyzed criterion are shown in the table below:

**Table 10.** Interaction effects for the SECOND analysed criterion.

| Interaction | A1C1 | A1C2 | A2C1 | A2C2 |
|-------------|------|------|------|------|
| Effect on the S/N ratio | -2.24 | 2.24 | 2.24 | -2.26 |
| Effect on the measured value | 0.19 | -0.19 | -0.19 | 0.19 |
4. Results

The two types of results can be best compared by using the graphs in figure 6. The higher the value of the S/N ratio, the lower the loss, i.e. the higher the production performance. The result are to be compared by means of the following figures: 7; 8, 9 and 10: Factor A (the hub type) is the most important one, it has the highest S/N ratio result, for the first criterion; thus for the first criterion A2 should be selected, and for the second A1, i.e. the highest values. Factor D (pressure) which acts directly on nonconformities, exerts an important influence on both the first and the second criterion, but mostly on the second one. For both criteria, D2 should be selected. For factor F (component pairing) the same things might be stated but it has a lower effect than previous factors. For the first criterion F2 should be selected and for the second, F1. Factor C (tappet lubrication) reduced dispersion and improves productivity. A1C2 combination, for both the first and second criterion, reduces the dispersion of the process results. For both criteria, C1 should be selected. Factor E (press stroke) and factor B (pressing force) exert low influence on the first criterion, and for the second criterion factor E has a slightly higher influence on result dispersion. For both criteria, B1 and E2 must be selected.

Figure 6. The effects of the first quality criterion on the signal-noise ratio (S/N) depending on the factors selected for the analysis.

Figure 7. The effects of the second quality criterion on the signal-noise ratio (S/N) depending on the factors selected for the analysis first quality criterion.

Figure 8. The effects of the first quality criterion on the value measured depending on the factors selected for analysis.
5. The levels of the global optimization factors for the S/N factors
The table below (Table 11) displays the criteria which must be optimized, containing the level of each factor which optimizes this criterion and the highest level of the S/N ratio result:

Table 11. The S/N contribution corresponding to the optimal level of each factor.

| No. | Factor description | Optimal level/ contribution | Criterion I | Criterion II |
|-----|--------------------|------------------------------|-------------|--------------|
| A   | Hubs               | Optimal Level               | 2           | 1            |
|     |                    | CONTRIBUTION                | 4.17        | 0.28         |
| B   | Pressing force     | Optimal Level               | 1           | 1            |
|     |                    | CONTRIBUTION                | 0.43        | 0.28         |
| C   | Tappet lubrication | Optimal Level               | 1           | 1            |
|     |                    | CONTRIBUTION                | 1.09        | 0.28         |
| D   | Pressing pressure  | Optimal Level               | 2           | 2            |
|     |                    | CONTRIBUTION                | 3.98        | 2.25         |
| E   | Part stroke        | Optimal Level               | 2           | 2            |
|     |                    | CONTRIBUTION                | 0.49        | 0.72         |
| F   | Component pairing  | Optimal Level               | 2           | 1            |
|     |                    | CONTRIBUTION                | 2.20        | 0.28         |

The table shows that factors A and F produce influence conflicts between the two quality criteria which must be optimized; the two factors require an arbitration so as to choose the level of each of the previous factors. Calculation are performed for the first optimization of the S/N ratio. For factor A, the sum of S/N ratio concentration is:

\[ A1: 4.17 + 0.28 = 3.89 \]
\[ A2: 4.17 - 0.27 = 3.89 \]

The sum of S/N ratio concentration for A2 is the highest, and thus level 2 will be selected (in the case of the two-level factors, the sums A1 and A2 are always opposed algebraic values).

\[ B1: 0.43 + 0.28 = 0.71 \]
\[ B2: -0.43 - 0.27 = 0.27 \]
\[ C1: 1.09 + 0.28 = 1.37 \]
\[ C2: -1.08 - 0.27 = -1.35 \]
\[ D1: -3.98 - 2.24 = -6.22 \]
\[ D2: 3.98 + 2.25 = 6.22 \]
\[ E1: -0.49 - 0.71 = -1.20 \]
\[ E2: 0.49 + 0.72 = 1.21 \]
\[ F1: -2.20 + 0.28 = -1.92 \]
The selections are presented in Table 12 below.

![Table 12. Experimental Values and Effects obtained.](image)

The resulted configuration: \textit{A2B1C1D2E2F2}. Therefore: The S/N ratio for Criterion I – level 20.2±0.1, is improved, the theoretical S/N ratio being 2.06, and the value theoretically measures -0.26, is lower than the average value. The S/N ratio for Criterion II – other defects is also improved, the S/N ratio theoretically resulted being 0.50, and the theoretically measured value -0.04, is very close to zero. This first optimization of the S/N ratio reveals the final variant for the levels of the analyzed factors and for the performance of the validation trial.

6. The validation of experiments. Conclusions and original contributions.

The obtained results are very close to those expected, the value of the S/N ratio is higher than the theoretical value both for the first and the second criteria.

For series production the following working procedure shall be implemented:

The problems caused by the ne hub shall be monitored with a view to its maintenance and for the feasibility of the process. The current hub is no longer utilized. The pressing force shall be set at 0.3kN. The tappets shall be lubricated before pressing.

The pressing pressure shall be of 6.6 bar. The press stroke shall be set at 32.7 mm. The component pairing shall be set in advance. This last factor should be analyzed because the component pairing is not at all time efficient, and thus solutions should be found with a view to optimizing time consumption.

![Table 13. The experiment validation.](image)
The validation experiment was performed again for the validation of the previously set levels, and the results are displayed in the table below (table 13).

One trial was performed for each of the criteria, the defect samples being taken as in the case analyzed above every two hours.

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