Automation systems in automatic assembling gear shaft output as car gearbox part at PT. Matahari Megah

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Abstract. This study is an observation and analysis about automatic assembling gear shaft output as car gearbox part that made at PT. Matahari Megah as a result of research. That automation product can reduce the assembly time from about 5 minutes to less than 45 seconds. Then the objectives in this case study are to describe assembly processes, how to choose censoring systems properly, and give recommendation in calculating compressive force for servo press mechanism. Automatic assembling gear shaft output has four main assembly stations consists of station OP 10, OP 20, OP 30, and OP 40. One of the most important element at that product is censoring system mounted at station check for checking the workpiece properly. The recommendations given are about the acrylic plate mounted at station check to reduce the amount of photoelectric sensor and equation for calculating compressive force for pressing gear and bearing to the output shaft appropriately.

1. Introduction

Transmission system is one of the most important part in a vehicle which consists of a lot of parts and it requires complicated and thorough design as well the assembly system. Automatic assembling gear shaft output is a line assembly system which is used to assemble output shaft as a part of car gearbox automatically that made at PT. Matahari Megah which an engineering-based company located at Jalan Raya Serang km 8,5 Kadu Jaya, Tangerang, Banten, Indonesia. The automation system that observed is assembly processes and conceptual planning for choosing sensors as one of the main element of automation. On the other hand, the recommendation in calculating compressive force is important because improper loading can cause defect on material both gear and shaft. Automatic assembling gear shaft output can reduce the assembly time from about 5 minutes [1] to less than 45 seconds. Automation systems are needed to generate the faster and more thoroughly in assembly system. The objectives in this case study are to describe how the assembly processes in automatic assembling gear shaft output works, to observe how to choose censoring systems properly and to give recommendation in calculating compressive force for pressing gear to the output shaft (interference fit) [2] as a result of research at PT. Matahari Megah.
2. Methods

Methods of collecting data is done by observation from conceptual design and planning of automatic assembling gear shaft output and trial for the censoring systems [3], [4]. The next method is data comparison to give the recommendation in calculating compressive force for interference fit [2]. Data used in calculating is estimation but it can be applied to the actual condition.

3. Result and discussion

3.1. Assembly processes

Automatic assembling gear shaft output is designed to avoid error during assembly process because there is difficulty in assembly process manually which needs high precision and accuracy. Furthermore, to press gear to the output shaft manually will take longer time. This machine has four main station to assemble each part to the output shaft, such as station OP 10, station OP 20, station OP 30, and station OP 40 [5].

![Figure 1. Each station sub output has different assembly process begins with checking pallete with parts of gear shaft output (workpiece) at station check, then station OP 10 assemble component of gear OP 10, station OP 20 assemble component of gear OP 20, station OP 30 assemble component of gear OP 30, and station OP 40 assemble component of bearing OP 40.](image1)

The workpiece assembled at the machine is a manual transmission which mainly consists of helical gears, synchronize, ring shaft snap, and bearing as shown in the figure below [5].

![Figure 2. Pallete with parts of gear shaft output ready to be assembled](image2)

![Figure 3. Gear structure on the output shaft at the end of assembly processes](image3)

The part number description of the workpiece can be shown in the Table 1 [5].
Table 1. Part description of gear shaft output

| Part Number | Description |
|-------------|-------------|
| 1           | Gear OP 10 consists of bush 1\textsuperscript{st} gear, gear 1\textsuperscript{st}, ring synchro no. 1, and hub assy synchro no.1 |
| 2           | Ring shaft snap OP 10 (component of gear OP 10) |
| 3           | Ring set synchro no.2 and gear 2\textsuperscript{nd} (component of gear OP 20) |
| 4           | Gear 3\textsuperscript{rd} driven (component of gear OP 20) |
| 5           | Ring shaft snap OP 20 (component of gear OP 20) |
| 6           | Gear OP 30 consists of gear 4\textsuperscript{th} driven and gear 5\textsuperscript{th} driven |
| 7           | Ring shaft snap OP 30 (component of gear OP 30) |
| 8           | Bearing OP 40 |
| 9           | Ring shaft snap OP 40 (component of bearing OP 40) |
| 10          | Output shaft |

Automation systems for assembling gear to the output shaft consists of four mechatronic elements. They are censoring systems for detecting part [3], jig mechanism for holding component rigid and prevent movement during working [6], walking beam conveyor for assembling and roller chain conveyor for non-assembling [7], and servo press mechanism for pressing gear to the output shaft with interference fit precisely [2], [8].

3.2. Censoring systems

Sensor is a device that receives and responds to signal or stimulus and it is closely related to control systems [9]. Censoring systems of automatic assembling gear shaft output is mounted at station check in order to avoid the probability of upside-down gear and make sure every part is in proper position. So, the sensor selection for this automation systems become important to be considered. For choosing the most appropriate sensor, there are some steps and parameters to be considered as shown below.

Figure 4. Flowchart for choosing the type of sensor from trial censoring systems of automatic assembling gear shaft output. To get the most appropriate sensor, it is important to check the sensor specification such as sensitivity, stability (short and long term), accuracy, speed response, stimulus range (span), resolution, dead band, cost, size, and weight [9]. The sensor mounted at station check have different type of sensor in accordance with the datum of workpiece than can be censored. Automatic assembling gear shaft output almost all utilize photoelectric sensor especially at station check.
Besides that, to reduce the amount of photoelectric sensor at station check because of too many incorrect possibilities, it will be recommended using acrylic plate model which has the geometry same as the workpiece with clearance about 2 mm up to 3 mm to the workpiece. The estimation of its dimension is 440 mm length, 360 mm height and 5 mm thickness. Acrylic plate is used to overcome the swapped-out probability of gear OP 20 number 3 and gear OP 20 number 4. Based on the geometry of the parts, if the gear is swapped out, it will push the acrylic plate and with proximity sensor enable that mechanism can detect the installation error by operator.

![Acrylic plate](image1.png)

**Figure 5.** Acrylic plate mounted at entry of station check

![Scheme of palate with workpiece enter the acrylic plate](image2.png)

**Figure 6.** Scheme of palate with workpiece enter the acrylic plate

### 3.3. Compressive force in servo press

Servo press is used to press gear OP 10, OP 20, OP 30, and bearing OP 40 to the output shaft with interference fit. Servo press is chosen because it uses software to control press speed and position which is much more flexible. Servo press have a closed-loop feedback system to more accurately control cycle rate and loads [10].

Automatic assembling gear shaft output has servo press DPS-301R4H-20FB type which has specification in the table below [8].

| Max. Rated Load (kN) | Max. Continuous Load (kN) | Max. Speed (mm/s) | Standard Stroke (mm) | Weight (kg) | Total Length (mm) |
|---------------------|---------------------------|-------------------|----------------------|-------------|-------------------|
| 30                  | 10.8                      | 200               | 200                  | 36.5        | 660               |

In order to calculate the compressive force for pressing gear and bearing to the output shaft which usually have medium carbon steel-based material, so is recommended to used Von Mises criteria to determine the press fit force. Von Mises criteria is used to probability case that the material has pass from elastic behavior immediately to the rupture [2]. There are three parameters to be considered in calculating servo press loading such as geometry tolerance and fit used in shaft and gear, frictional area, and yield strength of shaft and gear. Furthermore, loading characteristic for pressing the workpiece with interference fit can also be influenced by geometry (chamfer angle), material, and load-specific [11].

The recommended equation that consist of Von Mises criteria for calculating compressive force (the press fit force) gear and bearing to the output shaft is shown below [2].

\[
P = \frac{d}{E_0} \left[ \frac{d_o^2 + d_i^2}{d_o^2 - d_i^2} V_o \right] + \frac{d}{E_f} \left[ \frac{d_o^2 + d_i^2}{d_o^2 - d_i^2} V_i \right]
\]
Figure 7. Scheme of calculating press fit force

From the equation (1), the value of pressure of contact area between gear hole and shaft \((p)\) can be determined and it used to calculate the force necessary to press fit the parts \((F_p)\) [2].

\[
F_p = p \times \eta \times d \times \pi \times L
\]  

(2)

The calculation model of those equation can be applied to determine press fit force gear OP 30 to the output shaft at station OP 30. The dimension of gear OP 30 and output shaft in this model below is just estimation not actual one, but it can describe the calculating process to find press fit force in actual condition. In the Table 3, the variable given for gear is obtained from gear 5\(^{th}\) driven because it is weaker than gear 4\(^{th}\) driven in this operation.

| No. | Variables                             | Value  |
|-----|---------------------------------------|--------|
| 1   | Interference between gear and shaft   | 0.0025 |
| 2   | \(d\)                                 | 29 mm  |
| 3   | \(E_o\) (Material: SCM 440) [12]      | 200 GPa|
| 4   | \(E_i\) (Material: 655 M13) [13]      | 210 GPa|
| 5   | \(\nu_o\) [14]                        | 0.3    |
| 6   | \(\nu_i\) [14]                        | 0.287  |
| 7   | \(d_o\)                               | 54.5 mm|
| 8   | \(d_i\)                               | 5 mm   |
| 9   | \(\eta\) [15]                         | 0.16   |
| 10  | \(L\)                                 | 15 mm  |

Based on Table 3 and using equation (1), pressure of contact area is obtained 21.404 N/mm\(^2\) and using equation (2), the compressive force to press gear OP 30 to the output shaft is obtained 4.678 kN. So, the servo press DPS-301R4H-20FB chosen can press the gear OP 30 to the output shaft well.

4. Conclusion

An observation and analysis to automatic assembling gear shaft output is done to give recommendation for PT. Matahari Megah as a result of research. Assembly processes in automatic assembling gear shaft
output consist of station OP 10, OP 20, OP 30, and OP 40 which every station has four main elements of automation. They are censoring systems, jig mechanism, walking beam conveyor and roller chain conveyor, and also servo press mechanism. Some recommendations given involve acrylic plate design mounted at station check to reduce the amount of photoelectric sensor. Another recommendation is equation to calculate the compressive force for pressing gear and bearing to the output shaft with Von Mises criteria, so the process will be better and does not make defect for workpiece material.

### Nomenclature

| Symbol | Description |
|--------|-------------|
| $p$    | Pressure of the contact area between gear hole and shaft (N/mm$^2$) |
| $E_i$  | Shaft Young’s modulus (N/mm$^2$) |
| $I$    | Interference between gear hole and shaft (mm) |
| $d$    | Nominal diameter of gear hole and shaft (mm) |
| $E_o$  | Gear Young’s modulus (N/mm$^2$) |
| $F_p$  | Press fit force (N) |
| $d_o$  | Gear outer diameter (mm) |
| $\eta$ | Friction between gear hole and shaft |
| $V_o$  | Gear Poisson’s ratio |
| $L$    | Length of joint gear and shaft (mm) |

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