Study accuracy of a transportation system positioning of a test rig for automated mounting of luster terminals

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Abstract. A test rig for study of parameters of a process of automated assembly of luster terminals is designed and developed. The aim of the developed test rig is to study the accuracy of positioning of the transport system during the automated assembly process of the luster terminals. On the basis of data collected during the experiments, reliability analysis of the whole system has been made.

1. Introduction

Subject to automation is a plastic luster terminal with twelve inputs/outputs and mounting holes. It consists of a body in which brass details are placed with threads, each having two screws. An automated assembly system test rig had been designed and manufactured. The design is based on the test and assembly rigs presented in [1, 2, 3, 4, 5, 6, 8]. It has the following main modules (Figure 1 and Figure 2):

- Magazine - collectors (MC) for each of the three different elements, which are assembled into a final product "luster terminal" - a total of 10 pieces;
- A linear conveyor (LC), which moves the elements between the different positions;
- Interceptors for Element B and Element B (element A is cut off by MC by LC);
- Module for carrying out technological operation (TO) - assembling by threaded connection of 6 pcs. Elements B to 3 pcs. Elements B in position 4.

After the production and purchase of all the necessary items, a test rig for the automated assembly of the luster terminals is assembled. For programming of the stand the used program is “WinPISA 4.51” by "Festo" [7]. The input and output parameters are responsible for the information sent and received by all pickups, sensors and pneumatic cylinders, connected in the test rig. By using this information and depending on the value of each parameter, the blocks in the prepared block diagram are executed one after the other (Figure 5). Each individual block requires a specific value of one or several parameters in order to send the program signal for a subsequent operation to the test rig and to move to the next block where again the program will require specific values from the input parameters. After executing one program cycle, it starts again. Each pneumatic cylinder sends a signal of the position in
which it is located and this signal is constantly checked by the program. The same applies to the sensors responsible for the presence of elements in the MC. The test rig enters pause mode in case there are no items available in any of the MCs. The program set input and output parameters shown in Figure 3 and Figure 4.

Figure 1. 3D model of a test rig of automated luster terminal mounting [3]: 1 - MC; 2 - MC with interceptor; 3 - Two MCs with interceptor; 4 - Operating position for mounting screw-type element; 5 - Linear conveyor.

Figure 2. General view of the test-rig [3].

Figure 3. Input parameters [3].

Figure 4. Output parameters [3].

A block diagram of the operations performed in accordance with the operating cycle of the test rig is shown in Figure 5.
2. Methodology for experimental studies
When performing a certain number of observations or measurements on the subject, the results are obtained \(x_1, x_2, \ldots, x_q\), which form an elementary statistical aggregate (elementary statistical order) of volume \(n\). Observed or measured values are the final number of independent random variables that have the same distribution law as the random variable \(X\). The values \(x_i\), are called variations, and their ranking in ascending order - ranging order \([1, 2, 3]\).

![Figure 5. Block diagram of the program used [3].](image)

The resulting statistical set of values \(x_i, (i = 1, 2, \ldots, q)\) of the random value \(X\) together with the absolutes \(v_i\) and relative frequencies \(f_i\) form a statistical distribution law. The conversion count of \(X\) determines the absolute frequencies - \(v_i\), and their relationship to volume determines the relative frequencies \(f_i\). In that:

\[
\sum_{i=1}^{q} v_i = n, \quad \sum_{i=1}^{q} \frac{v_i}{n} = 1
\]

(1)

For a continuous random quantity, the statistic is broken down into classes (groups, orders) that are usually of equal lengths of intervals. In this way, an interval statistical sequence is obtained with \(k\) - class. The length of the interval \(h = x_i - x_{i-1} (i = 1, 2, \ldots, k)\) is determined by the dependence:

\[
h = \frac{x_{\text{max}} - x_{\text{min}}}{k} = \frac{\hat{h}}{k}
\]

(2)

Processing of experimental data \(x_i (i = 1, 2, \ldots, n)\) from small samples is performed in the following sequence of calculation, analysis, comparison of the relevant parameters (parameters):

- Variation order is created.
- The values of the numerical characteristics are determined.
- Absolute and relative mean errors for individual numerical characteristics are determined.
- The maximum absolute and relative errors of the individual numerical characteristics are determined by replacing the theoretical with the empirical values.
- Trusted limits and confidence intervals are determined at a preset confidence probability \(y\).
- The minimum sample size required is determined.
Statistical analysis and processing of experimental data \( x_i \) (\( i = 1, 2, \ldots, n \)) from large samples is performed in the following order:

- An interval statistic line is compiled and the range \( R \) is determined, the length of the interval \( h \) and the number of classes \( k \).
- The statistical set is represented graphically by an empirical distribution function, histogram and polygon.
- The values of the numerical characteristics are determined.
- The absolute and relative weighted errors for the individual numerical characteristics of disposition and scattering are determined.
- The values of the numerical characteristics of the moments (conditional start and center moments) are determined.
- Statistical estimates of asymmetry and excess (skewness and kurtosis) are determined.

By the type of the histogram and the polygon of the statistical law, the empirical values of asymmetry and excess and the physical essence and the physical sequence for obtaining and measuring the random quantity can be made the choice of the theoretical distribution law. For a more accurate assessment of the similarity of the experimental and theoretical distribution, the theoretical frequencies are calculated and a theoretical curve is constructed on the same scale [1, 2, 3].

2.1. Processing of results from engineering studies under "normal distribution"
The methodical sequence for constructing a normal distribution, which is most often subordinated to the distribution of random variables in all statistics, is subdivided into \( k \) classes with equal lengths of intervals \( h \); apply the exact values of the lower and upper limits of the classes \( x_{i-1} \) to \( x_i \); the average of each class and the corresponding frequencies are determined \( v_i \) [1, 2, 3]:

- the arithmetic mean is calculated:
  \[
  \bar{x} = \frac{\sum_{i=1}^{k} x_i v_i}{\sum_{i=1}^{k} v_i} \tag{3}
  \]
- the corrected dispersion and the mean quadratic deviation are calculated:
  \[
  s^2 = \frac{\sum_{i=1}^{k} (x_i - \bar{x})^2 v_i}{\sum_{i=1}^{k} v_i} - \bar{x}^2 \tag{4}
  \]
- Differences are determined for each class \( |\bar{x}_i - \bar{x}| \) and the values of the normalized deviations:
  \[
  t_i = \frac{|\bar{x}_i - \bar{x}|}{s} \tag{5}
  \]
- The tabulated values of \( f(t) \) for the found values of \( t \) are determined;
- the theoretical frequencies are determined and round up to an integer:
  \[
  v_i = \frac{n_h}{s} f(t) \tag{6}
  \]

The experimental (polygon) and the theoretical (equalized) distribution by normal law are constructed on the same scale: the differences between the experimental and the theoretical distribution curve are determined and the error is evaluated [1, 2, 3].

2.2. Result processing under the “exponential distribution” hypothesis
The methodology includes the following steps:

Step 1: Chronometry of fault-free time and time of failure.
Step 2: A statistical hypothesis on the exponential law of distribution of the probability of faultless work is adopted.
Step 3: Based on experimental data, the number of intervals for non-faultless operation \( n \) is determined and the limits for their modification \( t_i, i = n \).

The time of faultless operation \( \text{m}_{\text{mid}} \) is calculated according to:

\[
\text{m}_{\text{mid}} = \frac{\sum_{i=1}^{n} (\Delta N_i t_i)}{n} \tag{7}
\]

- Calculation of the statistical probability curve for faultless operation \( P(t_i) \)
  \[
P(t_i) = \frac{n-\sum_{i=1}^{n} (\Delta N_i t_i)}{n} \tag{8}
\]
- Calculation of the reliability function \( P(t) \)
  \[
P(t) = e^{m_{\text{mid}}} \tag{9}
\]
- Determining the average withdrawal time \( T_v \)
  \[
  T_v = \frac{\sum_{i=1}^{n} (\Delta N_i t_{\text{mid}})}{\sum_{i=1}^{n} (\Delta N_i)} \tag{10}
\]
  where: \( t_{\text{mid}} \) is the average of the time interval
- We define the failover flow parameter \( w \)
  \[
w = \frac{t_c}{m_{\text{mid}}} \tag{11}
\]
  where: \( t_c \) is cycling time
- Determination of actual productivity \( Q_f \)
  \[
  Q_f = \frac{1}{t_c + t_{\text{mid}}} = \frac{m_{\text{mid}}}{t_c (m_{\text{mid}} + T_v)} \tag{12}
\]
  where: \( t_{\text{mid}} \) are the stays of AT in the execution of one cycle.

- The results of the experimental studies are presented in a table.
- The experimental curve for faultless operation \( P(t_i) \) and the theoretical curve \( P(t) \) are built.
- The error is determined and compared to the allowable one.

3. Conducting the experiments and processing the results of the experimental research

The following experimental studies are performed:
- Position accuracy of the transport system.
- Reliability of the automated mounting test rig.

3.1. Position accuracy of the transport system

Experimental studies have been conducted to determine the positioning accuracy at different transfer speeds of the linear conveyor. Figure 6 shows the schematic diagram of the test setup for measuring positioning accuracy. The results of the experiments are shown in Table 1.
The normal distribution function $Y$ is calculated using the formula:

$$Y = \frac{1}{\sqrt{2\pi} \sigma^2} e^{-\frac{(\Delta x_{\text{mid}} - \Delta x_{\text{mid}})^2}{2\sigma^2}}$$

(13)

Table 1. Experimental research results.

| No of the interval | Interval [microns] | Frequency of occurrence n | $(\Delta x_{\text{mid}} - \Delta x_{\text{mid}})$ | $(\Delta x_{\text{mid}} - \Delta x_{\text{mid}})^2$ | $Y$   |
|-------------------|--------------------|---------------------------|-----------------------------------------------|-----------------------------------------------|-------|
| 1                 | -2 ± -1,5          | 3                         | 2.5                                           | 6.25                                          | 0.00036 |
| 2                 | -1,49 ± -1         | 5                         | 2                                             | 4                                             | 0.00389 |
| 3                 | -0,09 ± -0,5       | 10                        | 1.5                                           | 2.25                                          | 0.02503 |
| 4                 | -0,49 ± 0          | 14                        | 1                                             | 1                                             | 0.09454 |
| 5                 | 0,01 ± 0,5         | 28                        | 0.5                                           | 0.25                                          | 0.20985 |
| 6                 | 0,51 ± 1           | 16                        | 0                                             | 0                                             | 0.27374 |
| 7                 | 1,01 ± 1,5         | 12                        | -0.5                                          | 0.25                                          | 0.20985 |
| 8                 | 1,51 ± 2           | 8                         | -1                                            | 1                                             | 0.09454 |
| 9                 | 2,01 ± 2,5         | 3                         | -1.5                                          | 2.25                                          | 0.02503 |
| 10                | 2,51 ± 3           | 1                         | -2                                            | 4                                             | 0.00389 |

Figure 7 shows the processed experimental results for positioning accuracy of the transport system of the test rig in graphical form. The graph shows that the accuracy of the positioning is about $+2.5$ [microns], which corresponds to the positioning accuracy for mounting operations.
3.2. Determination of the reliability of the test rig for the automated assembly of luster terminals.
Experimental tests have been carried out for the reliability of the automated assembly system and the results are shown in Table 2.

Table 2. Experimental results for the reliability of the test rig.

| № of the interval | Interval boundaries [min] | Average interval value(t_i) | ∑ΔN_i, i=1÷n | N - ∑ΔN_i, i=1÷n | P(t_i) | t/m (mid) | P(t) |
|-------------------|---------------------------|-----------------------------|---------------|-------------------|-------|-----------|------|
| 1                 | 0 - 2                     | 1                           | 3             | 23                | 0,88  | 0,10      | 0,92 |
| 2                 | 2 - 4                     | 3                           | 2             | 5                 | 0,81  | 0,30      | 0,72 |
| 3                 | 4 - 6                     | 5                           | 4             | 9                 | 0,65  | 0,51      | 0,58 |
| 4                 | 6 - 8                     | 7                           | 1             | 10                | 0,62  | 0,71      | 0,47 |
| 5                 | 8 - 10                    | 9                           | 2             | 12                | 0,54  | 0,91      | 0,36 |
| 6                 | 10 - 12                   | 11                          | 3             | 15                | 0,42  | 1,12      | 0,25 |
| 7                 | 12 - 14                   | 13                          | 5             | 20                | 0,23  | 1,32      | 0,18 |
| 8                 | 14 - 16                   | 15                          | 2             | 22                | 0,15  | 1,52      | 0,12 |
| 9                 | 16 - 18                   | 17                          | 1             | 23                | 0,12  | 1,73      | 0,05 |
| 10                | 18 - 20                   | 19                          | 3             | 26                | 0,00  | 1,93      | 0,02 |

Figure 8. Results of experimental reliability studies.

On Figure 8 a graphical interpretation of the experiment results is presented. It can be seen that the error between the statistical and theoretical reliability curves is small, i.e. the two curves almost coincide.

For the automated assembly test rig under consideration:

\[ m_{\text{mid}} = \frac{256}{26} = 9,84 \text{ [min]} \]

\[ K_G = \frac{T_w}{T_w + T_v} = 0,97 \]

where \( T_w = m_{\text{mid}}; \ T_v \) – average recovery time after failure;

The coefficient \( K_G = 0,97 \) (for \( K_{G\min} = 0,8 \)), which fully satisfies the operational reliability requirements.

4. Conclusion

- A test rig for automated luster terminals mounting is developed.
From the experimental tests for the positioning accuracy of the transport system can be seen that
the positioning accuracy is around +2.5 [microns], which corresponds to the positioning
accuracy for mounting operations.

From the experimental tests carried out for the reliability of the developed test rig for automated
mounting of luster terminals is seen that the coefficient KG = 0.97 (for KGmin = 0.8), which
fully satisfies the operational reliability requirements.

The results of experimental studies that can be used in engineering practice are processed.

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