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ANALYSIS OF ERROR DURING MEASURING OF DIAMETER OF DIESEL ENGINE LINERS

Luko Milić
Ivona Milić-Beran
Mate Jurjević
University of Dubrovnik, Department of Mechanical Engineering
Cira Carica 4, HR-20000 Dubrovnik
Croatia (Hrvatska)

ABSTRACT
The task of the paper is to point out the confidence of data obtained during measuring of the diameter of marine diesel engine cylinder liners by contact measuring equipment, for the purpose of determining the state of liners and, accordingly, undertaking corresponding actions for the purpose of repairing the state of the same.
Liners of marine diesel engines are exposed to various influences during operation, on which wearing of liners largely depends. The decision on replacement of liners must be made on the basis of sufficient confident data, due to the price of liners, the necessary time for replacement because the engine is out of commission during that time, as well as due to the complexity of the procedure itself.
This paper identifies errors which arise during measuring. Thereby, the effect of a systemic and random error of direct measuring and the way of their elimination are analyzed.
By statistical methods, the coefficient of variation is calculated, which is a relative measure of dispersion of a numerical series on the actual example, and its implementation during comparison of dispersion of series with various arithmetic means and standard deviations is important.
Key words: measuring, error, diesel engine liner

1. INTRODUCTION
The cylinder liner may become cone-shaped, oval, and it can assume the form of a barrel. These states of the liner have a negative effect on the engine work process and on its efficiency. The diameter of the liner is checked by micrometer for measuring hollows with the 0.01mm accuracy. Measuring is carried out at several points, at least at three. Measuring is done in two vertical positions: forward - back and left - right. Wearing of the cylinder liner from 0.05 to 0.08 mm on 1000 hours of operation is considered as being within the allowed limits.

2. ERROR DURING MEASURING
The error of the measuring results is a deviation of the measuring results from the actual value of the measured size. The error is expressed in units of the measured size is the **absolute error**. It can be expressed by the formula:

$$\Delta x = x - A_o \quad (1)$$

A_o – actual value of the measured size
x – value obtained by measuring.
A relative error of measuring is a proportion of the absolute error and the actual value of the measured size.

$$\delta = \frac{\Delta x}{A_o} \quad (2)$$

A relative error is expressed as a dimensionless size or in percentages. The reciprocal value of a relative error expresses quantitatively the **measuring accuracy**. If the actual value of the measured size is unknown, then it is possible to appraise the measuring error only approximately.
Errors depending on the character of causes, which cause their arising, are divided into three groups: systemic, random and gross errors.
The systemic component of the error is constant or it changes according to a pattern during repeated measuring of one and the same size. Those errors can be set apart, and the results corrected.
Random measuring errors happen during multiple measuring of physical sizes due to random influences. Random errors are appraised by probability methods and by statistical mathematics.
Gross errors during measuring considerably exceed the expected error in the given conditions. They happen due to an error of perceiving, incorrectness of the equipment, sudden changing of the conditions during measuring, etc.
Their discovering is carried out by the probability criteria, which enable us to distinguish them from random errors.
On the basis of stated above, measuring errors can be expressed as follows: $\Delta x = \Delta x_1 + \Delta x_2$;
Δx_1 - systemic errors, Δx_2 - random errors.
The basic task of measuring is to obtain results with the smallest possible error.

2.1. Systemic errors and ways of their elimination

Systemic errors may deviate the measuring results considerably, so that it is necessary to point out the causes of their arising and use all the possible ways for their elimination. The following forms of systemic errors are distinguished: the method error, the equipment error and the reading error.
The component of a systemic error of reading arises during measuring in which the observer performs direct reading. Systemic errors are eliminated by correction or by a correction factor. Correction is carried out by adding of the correction value to the measuring result with the purpose of eliminating a systemic error, i.e. X_D=X+C; X – measuring result, C – correction, which has a constant value or is changed according to a specific dependence.
A correction coefficient is a number by which the measuring result is multiplied, for the purpose of eliminating a systemic error.

2.2. Random errors of direct measuring and ways of their elimination

Random errors arise under the influence of several various factors; they are sizes which influence the measuring results imperceptibly. The basis of the error theory is based on two hypotheses:

- with a large number of equally precise measuring, random errors are of similar value;
- major errors in relation to the absolute value are found more rarely than minor ones, i.e. the probability of appearing of an error are reduced with the increase of its numeric value.

During equally precise measuring of one and the same size carried out n-times, the results of particular measuring are marked with x_1, x_2, x_3, ..., x_n. It is presupposed that the values obtained by measuring do not have a systemic error. In that case, the error of the measuring can be expressed as:

$$\Delta x_i = x_i - A_o \tag{3}$$

The measuring results can be presented as: x_1= Ao+ Δx_1 ; x_2= Ao+ Δx_2 ; - - - - - - - -x_n= Ao+ Δx_n .
An error may have positive and negative values.
The average and actual value of the measured size can be found by the following expressions:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x \tag{4}$$

$$A_o = \bar{x} - \frac{1}{n}\sum_{i=1}^{n} \Delta x_i \tag{5}$$

For n → ∞, $A_o = \bar{x}$, while $A_o \approx \bar{x}$ for a limited number of measuring.
Determining of the approximate value of a measuring error can be done by the arithmetic value of measuring:

$$\Delta x_i = x_i - \bar{x} \tag{6}$$

Equally precise measuring of one and the same size is characteristic in errors of the results being very similar or evens the same, and they may appear repeatedly.

Table 2. The measuring results at the height of

h_1=100 mm

measuring	position A-A	Position B-B	error A-A	error B-B
1	150,02	150,04	0,004	0,004
2	150,02	150,041	0,004	0,005
3	150,02	150,041	0,004	0,005
4	150,02	150,039	0,004	0,003
5	150,019	150,04	0,003	0,004
6	150,019	150,033	0,003	-0,003
7	150,017	150,042	0,001	0,006
8	150,015	150,02	-0,001	-0,016
9	150,012	150,025	-0,004	-0,011
10	150,009	150,025	-0,007	-0,011
11	150,01	150,05	-0,006	0,014
12	150,012	150,032	-0,004	-0,004

h_2=200 mm

measuring	position A-A	position B-B	error A-A	error B-B
1	150,025	150,022	0,002	-0,008
2	150,02	150,028	-0,003	-0,002
3	150,016	150,021	-0,007	-0,009
4	150,02	150,02	-0,003	-0,01
5	150,021	150,029	-0,002	-0,001
6	150,02	150,035	-0,003	0,005
7	150,027	150,02	0,004	-0,01
8	150,025	150,038	0,002	0,008
9	150,021	150,041	-0,002	0,011
10	150,03	150,04	0,007	0,01
11	150,025	150,042	0,002	0,012
12	150,03	150,02	0,007	-0,01

In the marine engineering cabinet of the University of Dubrovnik, students of the II year of marine engineering performed measuring on the cylinder liner of engine, Figure 3. Measurements were performed at two heights, h= 100 mm and h=200 mm, and at two positions A-A and B-B.
During measuring carried out at the height of h=100 mm, the arithmetic mean of the A-A measuring position comes to 150.016, and that of B-B, to 150.036. The standard deviation is an average deviation of the value of the numerical characteristic from the arithmetic mean and it is expressed in the same measuring units as the characteristic [4.]. The standard deviation for measuring carried out at the position A-A is 0.004, and at the position B-B, it is 0.009.

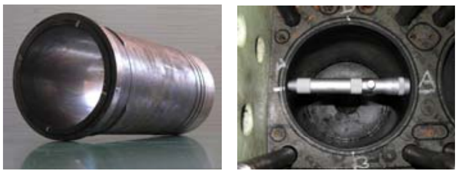

Figure 1. Cylinder liner of engine.

During measuring carried out at the height of h=200 mm, the arithmetic mean of the A-A measuring position comes to 150.023, and of the B-B position to 150.030. The standard deviation for measuring carried out at the A-A position is 0.004, and at the B-B position 0.009.
On the basis of the sample, interval appraisal of the average value of the engine cylinder liner diameter was carried out at the 95%-th level of confidence, and the following results were obtained:

a) For measuring at the A-A position and the height h = 100 the values of limits within which the arithmetic mean of the liner diameter are [150.013; 150.019].
b) For measuring at the B-B position and the height h = 100 the values of limits within which the arithmetic mean of the liner diameter are [150.030; 150.041].
c) For measuring at the A-A position and the height h = 200 the values of limits within which the arithmetic mean of the liner diameter are [150.021;150.026].
d) For measuring at the B-B position and the height h = 200 the values of limits within which the arithmetic mean of the liner diameter are [150.024; 150.035].

The coefficient of variation is a relative measure of dispersion of a numerical series, and its implementation in comparison of dispersion of series with various arithmetic means and standard deviations is important.
The coefficient of variation for the A-A position at the height of h=100 amounts to 0.0028%, and at the height of h=200 it is 0.0029%, which shows that dispersion of the measuring results at the height of h=100 is higher than dispersion of the measuring results at the height of h=200.

The coefficient of variation for the B-B position at the height of h=100 amounts to 0.006%, and at the height of h=200 it is 0.0058%, which shows that dispersion of the measuring results at the height of h=100 is higher than dispersion of the measuring results at the height of h=200.
On the basis of the values of the coefficient of variation, it can be concluded that deviations are very small at all positions and heights.
According to the obtained results for limits of the 95%-th interval of the appraisal of the average cylinder liner diameter and coefficients of variation, it can be concluded that the performed measuring are sufficiently correct for obtaining a quality insight in the state of the marine diesel engine liner.
For the needs of engineering practice, the measuring results which deviate from the arithmetic mean by more than three standard deviations are rejected. During a small number of measuring for determining the accuracy of the results, the V. N. Romanovski's criterion is used, which is based on the Student's distribution [4]. On the basis of his studies, the Table of relative values of gross errors $\left(t_k = \frac{\varepsilon_k}{\sigma_s} \right)$ was obtained, depending on the given probability of appearing of errors and the number of measuring n. In our example, for the probability of appearing of the error 0.05 and 10 measuring, the value t_k amounts to 2.37.
For measuring at the height of h=100, A-A position, if the measured values deviate from the arithmetic mean by more than ε_k=0.0098, it is considered that a gross error was made and such values are rejected. For measuring at the height of h=100, B-B position, the critical limit is ε_k=0.020.
For measuring at the height of h=200, A-A position, if the measured values deviate from the arithmetic mean by more than ε_k=0.0099, it is considered that a gross error was made and such values are rejected. For measuring at the height of h=200, B-B position, the critical limit is ε_k=0.020.

3. CONCLUSION

The purpose of this paper is to determine the confidence of measuring of the marine diesel engine cylinder liner by the contact measuring equipment for the purpose of appraising its state and making a decision on the need of undertaking corresponding actions.
Ten students carried out the measuring in order that a subjective approach of various performers carrying out measuring on a ship would be included.
On the basis of the comparison of the values of coefficients of variation, it can be concluded that deviations are very small at all positions and heights.
For the needs of engineering practice, the measuring results which deviate from the arithmetic mean by more than three standard deviations are rejected.
According to the obtained results for limits of the 95%-th interval of the appraisal of the average cylinder liner diameter and coefficients of variation, it can be concluded that the performed measuring are sufficiently correct for obtaining a quality insight in the state of the marine diesel engine liner.
From the obtained results and the performed analysis of the obtained results of the value of the engine cylinder liner diameter, it can be concluded with the 95% confidence that the measuring of cylinder liners which are carried out aboard a ship are sufficiently accurate for making decisions on undertaking the necessary measures.

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