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On approximation of engine combustion pressure data measured by means of an electronic indicator

SUMMARY

In the paper the application of three calculation methods for approximation of engine combustion pressure curves and their 1st and 2nd derivatives on the basis of discrete data obtained from an electronic indicator, was presented and discussed by using example calulations. In the considered cases all the three methods practically ensured adequate approximation accuracy at nodes.

INTRODUCTION

Application of an adequate method to approximate the engine combustion pressure curve pays a very important role in preparation of an open indicator diagram when portable electronic indicator is used. UNITEST-205 Marine Diesel Engine Tester is an example of this type indicators. In UNITEST-205 indicator an indirect method is used for determination of a reference point on the open indicator diagram, hence choice of a proper method of approximation is essential for positioning and evaluation of the diagram by using 1st and 2nd derivatives calculated for a selected part of the pressure curve [1]. Correction of measured data by means of approximation methods is aimed to eliminate measurement noise, not significant for engine combustion analysis, but important for calculation of derivatives.

In this paper three methods – namely those using Lagrange, spline and trigonometric polynomials – are considered to approximate the combustion pressure function on the basis of discrete data acquired with the use of the electronic indicator, and to calculate the first and second derivatives of the function.

Results of pressure measurements are stored in the indicator's memory as pairs of values of the pressure-time coordinates $\{p_i, t_i\}$. It is possible to obtain the pressure data in the intervals $(t_{i+1} - t_i)$ equal to one degree of crank angle. Examples of pressure indication results are presented in Fig.1 and 2. The pressure values are given in internal indicator units. The real value of pressure is the product of the indication readout and a scale factor value set during calibration of the indicator. The same mode of presentation is used for all presented pressure curves and derivatives.

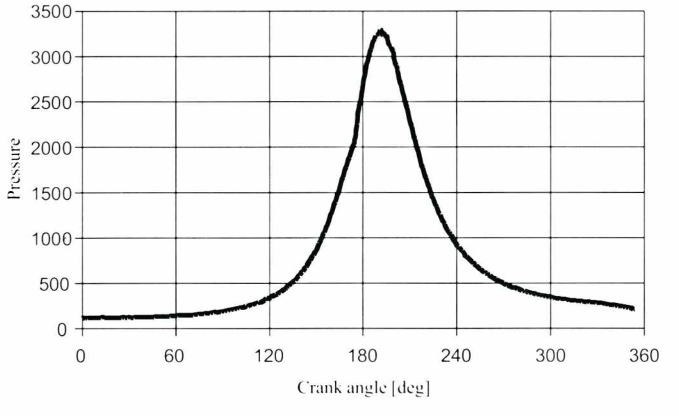

***Fig.1.** Indicated combustion pressure diagram for Z40/48 SULZER engine*
***Note :** Pressure is given in internal indicator units*

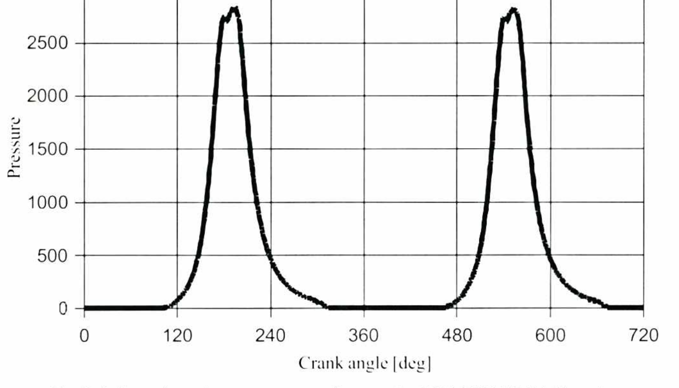

***Fig.2.** Indicated combustion pressure diagram for L50MC MAN-B&W engine (during 2 cycles)*
***Note :** Pressure is given in internal indicator units*

APPROXIMATION OF COMBUSTION PRESSURE CURVE BY USING LAGRANGE AND SPLINE POLYNOMIALS [4]

Calculation results below presented concern combustion pressure curve of S20 Sulzer engine (at 50% load and 900 rpm speed). The example calculations were performed for 60 measurement points, which corrresponds to 60 deg crank angle. An initial point is so selected that the maximum pressure is located in the middle of the range. This way zeroing of the second derivative can be expected in this area [2].

The computer program SPLIN [5] based on spline functions was used to calculate the approximation coefficients. This program makes it possible to :

- read the entry data (from files generated by indicator)
- declare polynomial order, number of continuous derivatives and number of nodes
- calculate values of approximating function
- evaluate quality of approximation
- calculate of polynomial coefficients
- visualize calculation results by generating appropriate graphs
- store all data.

Another programs which use are also described in this paper, have similar options.

Polynomial approximation based on Lagrange method

The 6 th order Lagrange polynomial was used for aproximation of the measured data. Its results are presented in Fig.3 where the measured data are represented by a black curve, and calculated polynomial – by a grey curve. The calculated mean square error of the approximation amounted to 1.3%.

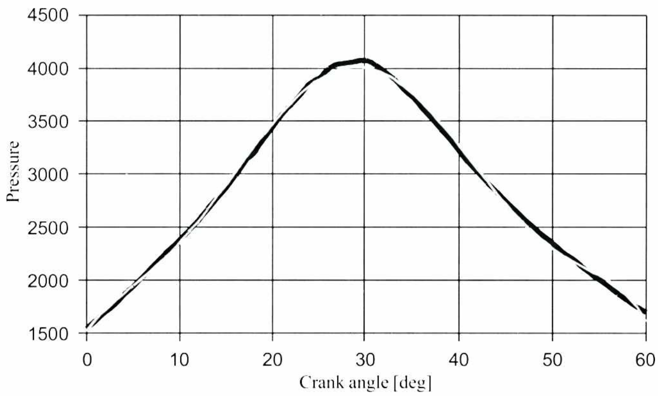

Fig.3. Comparison of the measured data (black) and the calculated Lagrange polynomial curve (grey)
Note : Pressure is given in internal indicator units

Polynomial approximation based on spline function

The cubic spline function was used with nodes placed at : 15th, 25 th, 35 th and 45 th point positions. The approximation results are presented in Fig. 4. The differences between respective values of both curves are less than the graph resolution. In this case the calculated mean square error amounted to 0.7% only, i.e. twice less than that of the previous example.

Calculation of the first and second derivatives

As it was mentioned earlier, the coordinate angle values in which the first and second derivative values are equal to zero, are essential for positioning indicator diagram.

Form of 1st and 2nd derivatives calculated for the approximation polynomials given in Fig. 3 and 4, are presented in Fig. 5, 6, 7 and 8, respectively.

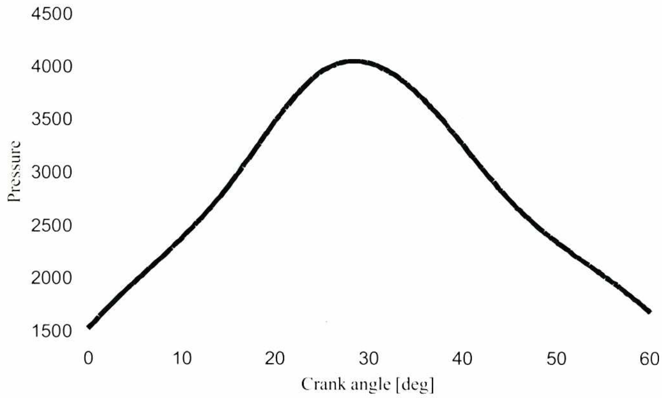

Fig.4. Comparison of the measured data and the calculated spline polynomial curve
Note : Pressure is given in internal indicator units

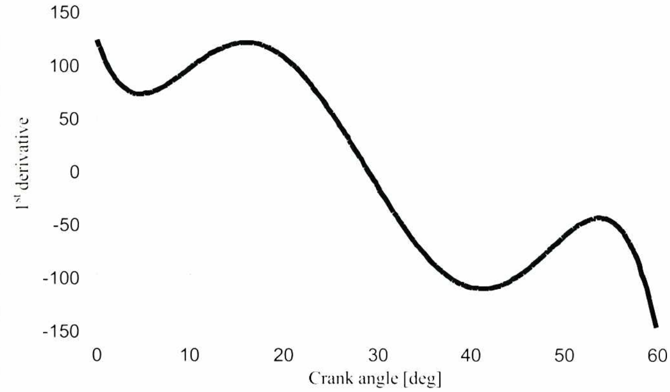

Fig.5. 1st derivative of the approximation curve calculated by using Lagrange polynomial

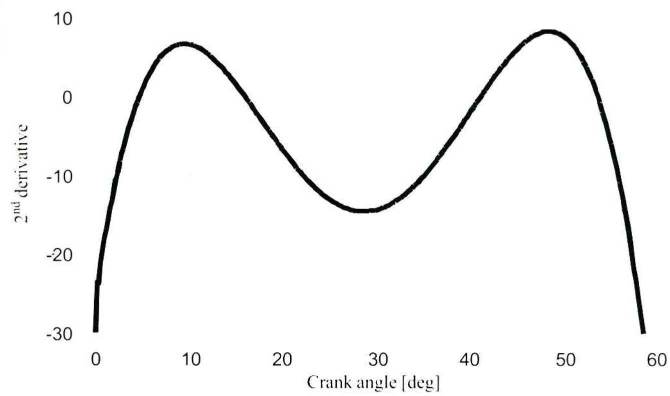

Fig.6. 2nd derivative of the approximation curve calculated by using Lagrange polynomial

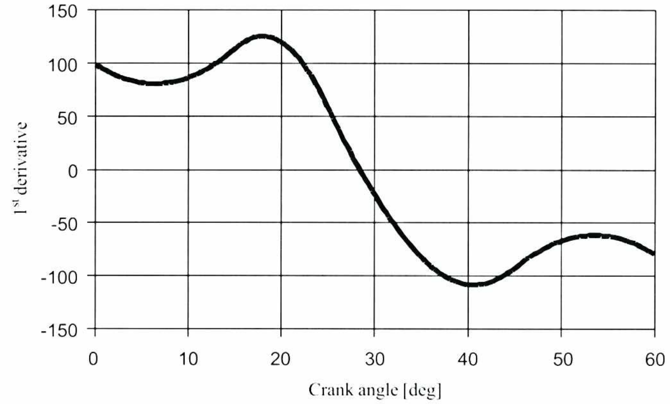

Fig.7. 1st derivative of the approximation curve calculated by using spline polynomial

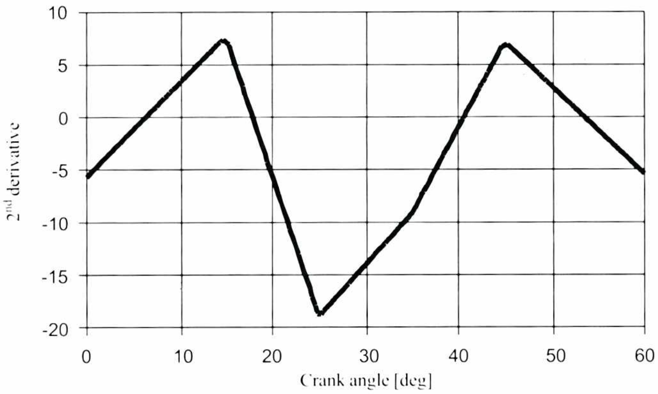

Fig.8. 2^{nd} derivative of the approximation curve calculated by using Lagrange polynomial

The difference between the calculation results obtained from the two methods is less than 0.61 deg for the first derivative. It means that the approximation error is less than the measurement resolution.

The difference is bigger in the case of the second derivative calculation. In both approximation cases two zero points (inflexion points) appeared. The points situated on the concave part of the curves (see Fig. 6 and 8) are more important for further implementation of the data. Their corresponding values are 16.0 deg and 17.89 deg. It means that the calculation result depends on the used method.

APPROXIMATION OF COMBUSTION PRESSURE CURVE BY USING TRIGONOMETRIC POLYNOMIALS

Trigonometric approximation is very convenient tool for evaluating of periodic phenomena [5] , [6].

Generally the approximating formula is as follows :

$$f(x) \approx \frac{a_0}{2} + \sum_{i=1}^{N} \left(a_i \cos\frac{i\pi x}{L} + b_i \sin\frac{i\pi x}{L} \right)$$
$$(-L < x < L)$$

In this paper it was assumed that :

- the crank angle range is ± 30 deg around the maximum pressure point
- an approximation polynomial of 11^{th} order is selected. *(The respective approximate calculations were carried out by means of a program based at [4] and [6]).*

Results of the calculations are shown in Fig.9 and 10.

Shifting of the crank angle axis, to obtain location of the zero point in the middle of the graph, is the consequence of the used formula (see above).

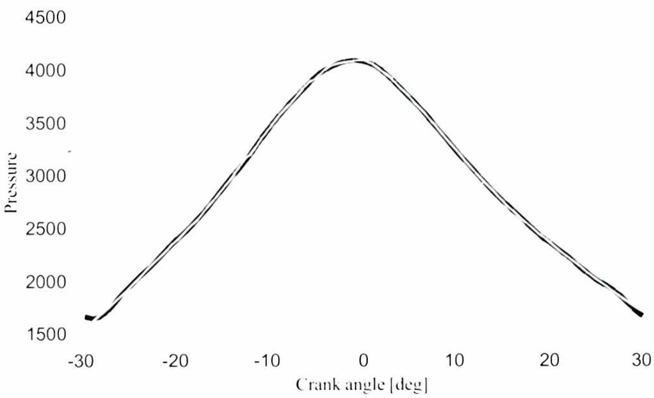

Fig.9. Comparison of the measured data (black) and the calculated trigonometric polynomial curve (grey)
***Note :** Pressure is given in internal indicator units*

In the case in question the mean square approximation error is less than 0.7%. Accuracy of this approximation is similar to that obtained by using the cubic splines (see Fig.4).

Respective derivative curves are presented in Fig.10.

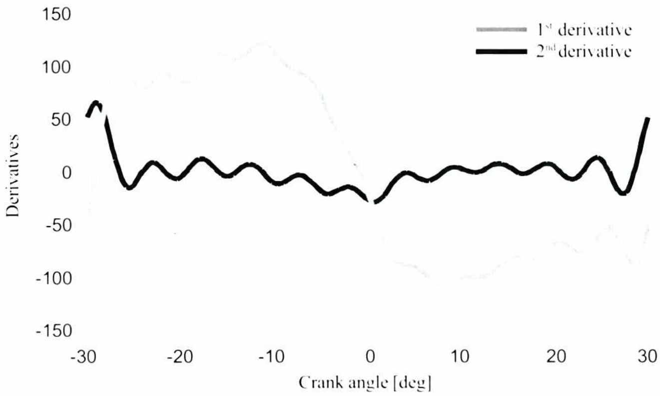

Fig.10. 1^{st} (grey) and 2^{nd} (black) derivatives of the approximation curve calculated by using trigonometric polynomial

Form of the 1^{st} derivative curve is similar to that obtained by using the previous methods. The respective zero-point coordinate values calculated for all three considered cases are as follows :

- ★ for Lagrange polynomial approximation : 28.96 deg
- ★ for cubic spline approximation : 28.38 deg
- ★ for trigonometric approximation : 29.17 deg.

The form of the 2^{nd} derivative curve for trigonometric polynomial is different from those calculated by means of the previously considered methods. In this case higher constituents (harmonics) of the approximation function cause that the 2^{nd} derivative values oscillate about zero therefore determination of the zero point is dubious.

CONCLUSIONS

On the basis of the presented example calculations it can be concluded that :

- ❍ Practically all considered approximation methods (i.e. those using Lagrange polynomial, spline polynomial and trigonometrical polynomial) applied to the example calculation cases ensure adequate accuracy of approximation at nodes.
- ❍ Form of combustion pressure curve is reproduced with a sufficient accuracy as the calculated mean square error is less than 2% in all considered cases.
- ❍ The best method for calculation of the 1^{st} and 2^{nd} derivatives of the approximation functions is that based on spline function.

Appraised by Romuald Cwilewicz, Assoc.Prof.,D.Sc.

NOMENCLATURE

a_0 , a_i , b_i	–	calculated coefficients
f(x)	–	approximated function
x	–	argument
L	–	range of calculation
N	–	order of polynomial

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