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Data acquisition and analysis of an exclusive measuring machine for marine engine's cams

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ABSTRACT

In this paper, data acquisition and analysis of a measuring machine for marine engine's cams are discussed. A rotary encoder and linear scale of the machine to measure angular and linear displacement, respectively, are interfaced to the PC via an encoder board with 2 channels. The design and measuring data are interpolated by cubic spline curves to compute the precision error which is defined by the maximum and minimum distances between two curves. The minimum zone fit of ISO is employed to evaluate the geometric deviation. The developed system takes only 5 minutes to measure and analyze the precision error while the CMM takes over 1 hours even with a skilled operator.

Key Words : Cam, CMM, Linear scale, Geometric deviation, Minimum zone fit

1. Introduction

Korea has the largest volume of ship construction in the world, and thus, there is great demand for marine engines. A cam in a marine engine opens and closes the pocket valve in the engine. There are two types of cams; the exhaust cam and the fuel cam as shown in Fig. 1.

The cams for marine engines are bigger than those used for automobiles or industrial machines, and due to affecting the efficiency and performance of the engine, they require high machining accuracy.

Cams are manufactured by first, external turning, followed by milling, heat treatment, and finally the grinding, to produce the final profile. After processing, the precision of the final profile should be measured. If it is measured manually, a dial gage is used, dividing the cam by the angle-indexing head. In case where the measurement is done automatically, a 3-dimensional coordinate measuring machine(CMM) can be used. However, the CMM requires a skilled technician as well as longer measurement time.

Therefore, to minimize the time required for profile measurement and data analysis, a dedicated measuring machine is used to measure the contour of the cam with a probe by rotating the cam, as shown in Fig. 2.

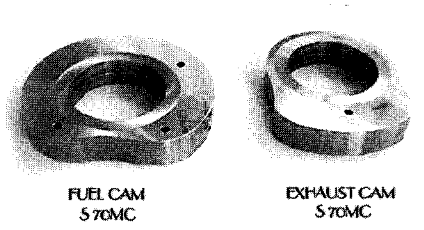

Fig. 1 Cams for a marine engine

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Fig. 2 Cam-exclusive measuring machine

The most important feature of the dedicated measuring machine is that its probe is attached by a circular plate of the same size as that of the roller used in actual engines. Since the design data of the cam profiles are given as a trajectory of the center of the roller, it is quite easy to compare the measured and designed data.

In the coordinate measuring machine, on the other hand, when the measuring probe contacts the cam profile directly, several accompanying operations are needed to compare the design data and measurement data.

As for the cam-exclusive measuring machines, the control mechanism is not known in detail. Furthermore, there is much difficulty in interpreting the measured data, because the definition of the geometric error of the cam profile is not widely known, whereas the definitions of geometric errors such as straightness, roundness, flatness are well known.

Therefore, this paper develope a method to calculate the precision of the cam by analyzing measured data according to a minimum zone fit[2], which is the ISO standard for geometric deviation.

2. Data aquisition and analysis

2.1 Principle of the measuring machine

The marine engine cam used in this paper is the disk cam with a roller follower as shown in Fig. 3. Design data consist of a rotation angle and a lift value of the cam for ascending and descending strokes, and they are identical to a pitch curve which represents the trajectory of the center of the roller[3].

As shown in Fig. 2, the measuring machine is composed of a driving part that rotates the cam and a measuring part that carries out the measurement. A circular plate of the same size as that of the roller used in real engines adheres to the end of the measuring machine to obtain the measured data. A rotary encoder built in the motor and a linear scale built in the measuring part acquire the amount of rotation and linear displacement, respectively (Fig. 4(a)).

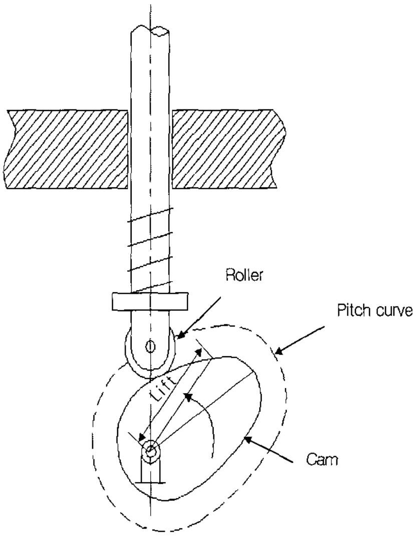
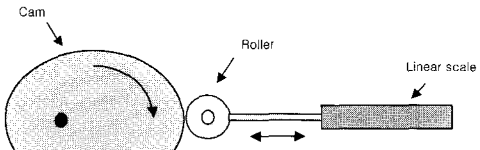


Fig. 3 Cam mechanism

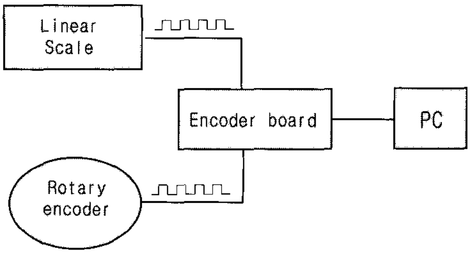
2.2 Measurement data aquisition

Because the output signals of the rotary encoder and the linear scale are in pulse form, an encoder board that supports more than 2 channels is engaged to obtain the signals(Fig. 4(b)).

Fig. 5 shows the measuring process: when the rotation angle calculated from the pulses of the encoder reaches a certain predetermined value, the rotational angle and displacement are saved as measurement data.



(a) Mechanism of a cam measuring machine



(b) Data acquisition

Fig. 4 Principle of a cam measuring machine

2.3 Data Analysis

Although there are several methods to deal with the geometrical error of the machined parts, ISO and KS B 0425 prescribe the use of the minimum zone fit[3]. The minimum zone fit is the method for evaluating the minimized size of the profile that has deviated from the designed profile geometrically. Note that the minimum zone fit does not regulate the method of measurement but only evaluates the measured data.

When this is applied to a cam profile, we try to find two enclosing cam curves that not only are co-centric but also include all the measured data in a minimum distance. However, because innumerous searches must be done to find both the co-center and orientation, it is assumed that the center of measurement data is identical to that of the design data. Under this assumption, the calculation process of the maximum/minimum error of the measured data is explained below:

1) Perform cubic spline interpolation of design and measurement data(Fig. 6(a),(b)).
2) Calculate normal vector at each design data point.
3) Find an intersection point between the normal vector and measurement data spline curve.
4) Calculate the error(ξ_i).
5) Repeat the procedures 1) ~ 4) to all the design data points.

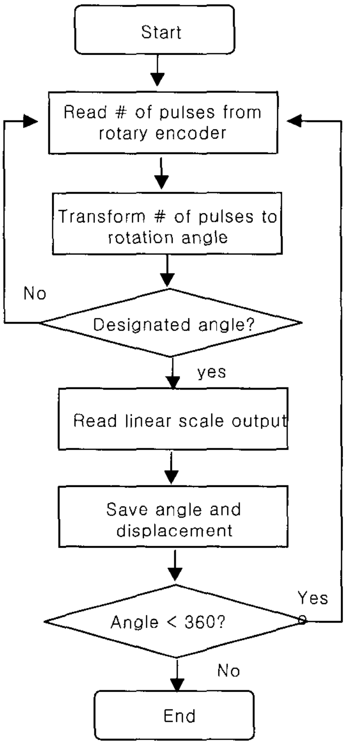


Fig. 5 Flow chart of data acquisition

2.3.1 Cubic spline curve interpolation

In a cubic spline curve defined by measurement data, the equation for segment i is represented by

$$r_i(u) = UCS_i \quad (i = 1, 2, \ldots, n-1) \qquad (1)$$

where

$$U = [1 \ u \ u^2 \ u^3], \ C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -3 & 3 & -2 & -1 \\ 2 & -2 & 1 & 1 \end{bmatrix},$$

$$S_i = [P_i \ P_{i+1} \ w_i t_i \ t_{i+1}]$$

To apply equation (1) to design and measurement data, it is necessary to solve the inverse of 360 x 360 square matrix. Tomas method[5] utilizing the properties of the tri-diagonal matrix is powerful in computing this large inverse matrix.

2.3.2 Calculation of a normal vector

With the cubic spline curve of the design data, the normal vector at each design data(p_i) is derived easily from the tangent vector t_i. Let n_i denote the unit normal vector of the design data p_i, then the straight line l_i including the normal vector is (Fig. 7)

$$l_i = p_i + t \cdot n_i \tag{2}$$

2.3.3 Intersection point

Since the measurement data spline curve is expressed as a combination of segments between each data, the segment where the spline curve and the straight line l_i. must be found. Let vectors a, b denote the vectors of two measurement data (m_j, m_{j+1}) with its origin p_i, respectively. Then, an intersection occurs between the spline segment and the straight line l_i if the following equation (3) is satisfied, and the intersection point is then calculated by the popular Newton-Raphson method.

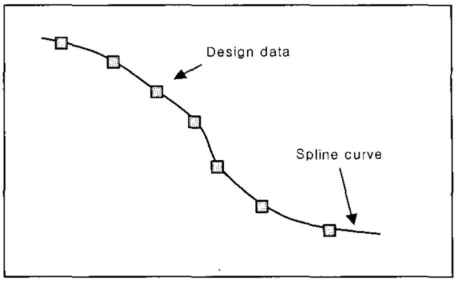
$$(a \cdot n_i)(b \cdot n_i) < 0 \tag{3}$$

Let the error(ε_i) represent the distance between the design data and the intersection point. It is defined as positive(+) if the intersection point is outside the design curve and negative(-) if it is located inside the curve. In Fig. 7, for example, all the errors have positive values because all the respective measured data are located outside the designed data.

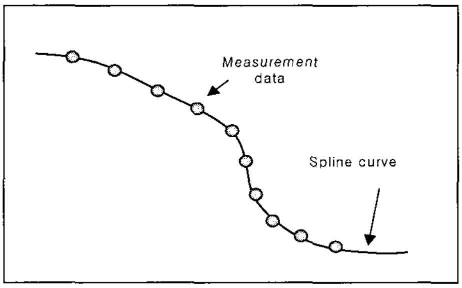
2.3.4 Maximum/Minimum error

The maximum and minimum error within the definition interval(R) can be defined as follows;

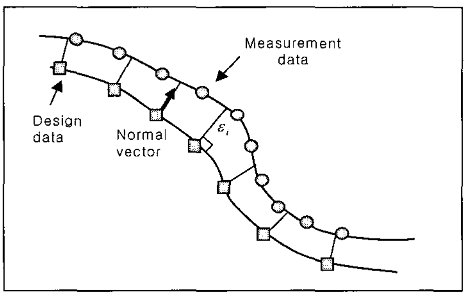
$$\begin{aligned} \varepsilon_{\min} &= Min(Minimum(\varepsilon_i), 0), \quad && i \in R \\ \varepsilon_{\max} &= Max(Maximun(\varepsilon_i), 0), \quad && i \in R \end{aligned} \tag{4}$$



(a) Spline curve of design data



(b) Spline curve of measurement data



(c) Computation of errors

Fig. 6 Procedures of error computation

The interval R represents a certain range on the designed data, a range needed to calculate the maximum/minimum errors. Note that in equation(4) the maximum error value is defined as 0 if all the errors are negative in R, while the minimum error is defined as zero if all the errors are positive.

With the maximum and minimum error values of each points, the total error(E) within R can be calculated by equation(5).

$$E = \varepsilon_{\max} - \varepsilon_{\min} \tag{5}$$

Two enclosing cam curves including all measurement data can be created with $\varepsilon_{\max}, \varepsilon_{\min}$. However, the distance between these two curves may not guarantee the minimum zone fit of ISO.

Actually, it is very difficult to make the origin of the measurement data and design data identical during the measuring process; this difficulty results in errors between the initial measurement data and the design data. Therefore, to find the minimum zone, an optimization process is necessary.

The optimization process is performed by rotating the measured data in the CW and CCW directions by fine angle steps to minimize the total error values.

Further, note that the required precision of the cam profile is given in Table 1, which shows that the total error should be under 0.05, between two consecutive measurement points, 0.09 among four consecutive measurement points, 0.35 among sixteen consecutive measurement points, and 0.4 among all measurement points.

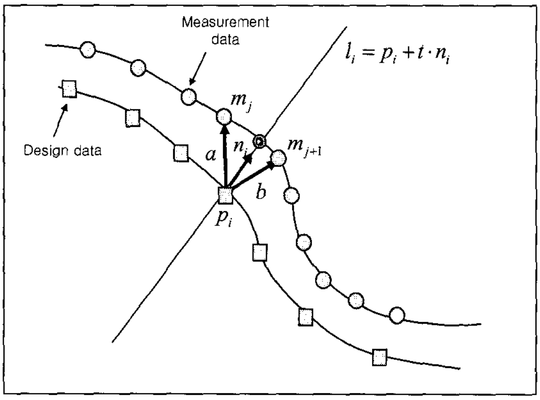


Fig. 7 Computation of intersection point

Therefore the measurement data should be checked to determine whether the errors satisfy Table 1 by rotating them in fine angle steps.

Table 1 Permissible errors

Permissible errors				
Angle	360°	15°	3°	1°
Error	0.4	0.35	0.09	0.05
Unit	mm			

3. Implementation Example

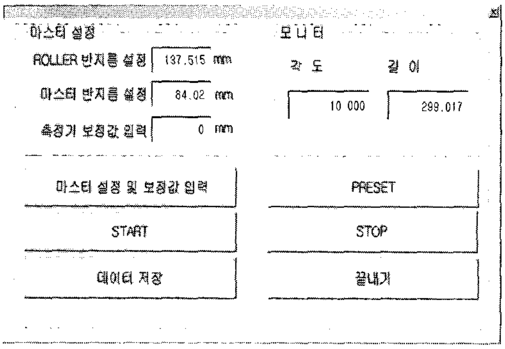
The methodology developed, which was implemented by Visual Basic on a Pentium-IV PC, is composed of a data acquisition module and a precision calculation module. The specifications of the rotary encoder and linear scale used in this study are shown in Table 2.

Table 2 Spec. of linear scale and rotary encoder

Linear scale		Rotary encoder	
stroke	220mm	resolution	2048(P/R)
accuracy	±5μm	output phases	A,B,Z
resolution	1μm	output type	totem pole

Fig. 8 shows that the cam profile data are measured by reading the output signals of the rotary encoder and linear scale. By inputting the radius value of the roller-probe and the master cam and pressing the start button, the angle and the length values are presented on the screen.

To obtain the repetitive precision of the measuring machine, measuring process is performed repeatedly. As a result, the repetitive error of each point reaches within ±2μm, which shows that the repetitive error has little effect on the total error compared to the allowable error in Table 1. Nonetheless, for cases that may require high accuracy, users can set the repetition times of measurements as required.



ROLLER 반지름 설정 137.515 mm
마스터 반지름 설정 84.02 mm
측정기 보정값 입력 0 mm

각 도 10 000
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Fig. 8 Data acquisition module

The measurement data are compared with the designed data as shown in Fig. 9. In the Figure, the one located in the middle among the three cam curves is the designed data and the others on both sides are the cam curves that were offset by the maximum allowable error. Fig. 9(a) shows the profile before optimization, whereas Fig. 9(b) shows the profile after optimization, which satisfies the minimum zone fit. The result shows that the total error is reduced to 0.12 from 1.12 after optimization.

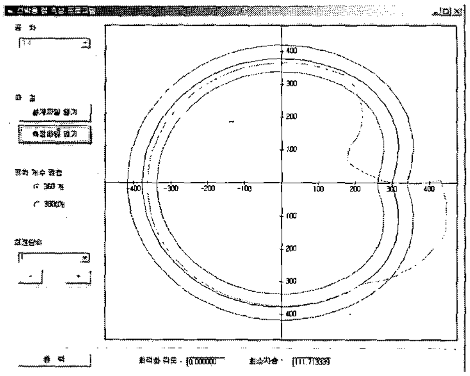
Fig. 10 is the result of total error calculated within the defined section, according to the standards of Table 1. The total error were calculated from each range of 1°,3°,15°, and 360° for all measured data. In cases where the error exceeded the allowable error, the measured position was marked accordingly.

4. Conclusion

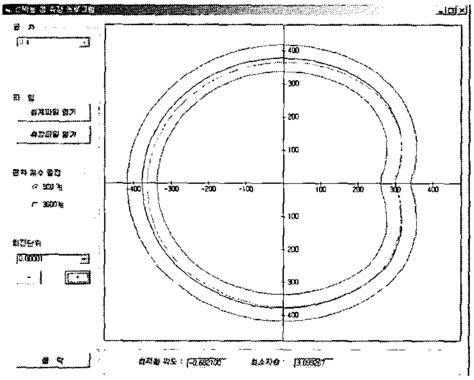
In this study, we discussed data acquisition and analysis of an exclusive measuring machine for marine engines. The conclusions are as follows.

1) It was possible to directly acquire output signals from the rotary encoder of the drive motor and the linear scale in the displacement device by using a 2-channel encoder board.
2) The minimum zone fit, an ISO standard on geometrical deviation, was applied, and the optimization process was carried out to find the orientation of minimum total error after calculating the errors for each measured point in the designed data
3) The measurement and analysis of cam profiles, it takes more than 7 hours[6] when manually measured. Even with a 3-dimensional coordinate measuring machine, it takes more than an hour. However, we were able to reduce the time to less than 5 minutes with the exclusive measuring machine.

In this study, it was assumed that the center location of the cam of the measured point and that of the designed point were identical to reduce the searching time. Therefore, an advanced algorithm on geometrical deviation calculation of the cams by minimum zone fit should be developed further in the future.

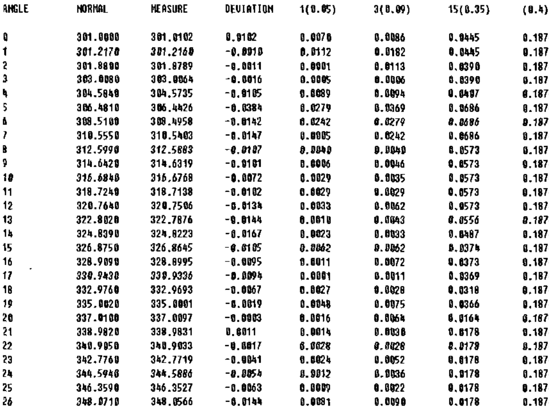


(a) Before optimization



(b) After optimization

Fig. 9 Display of the design and measurement data



ANGLE	NORMAL	MEASURE	DEVIATION	1(0.05)	3(0.09)	15(0.35)	(0.4)
0	301.0000	301.0102	0.0102	0.0070	0.0086	0.0445	0.1874
1	301.2170	301.2160	-0.0010	0.0112	0.0182	0.0445	0.1874
2	301.8800	301.8789	-0.0011	0.0001	0.0113	0.0390	0.1874
3	303.0080	303.0064	-0.0016	0.0005	0.0006	0.0390	0.1874
4	304.5840	304.5735	-0.0105	0.0089	0.0094	0.0407	0.1874
5	306.4810	306.4426	-0.0384	0.0279	0.0369	0.0686	0.1874
6	308.5100	308.4958	-0.0142	0.0242	0.0279	0.0686	0.1874
7	310.5550	310.5403	-0.0147	0.0005	0.0242	0.0686	0.1874
8	312.5990	312.5883	-0.0107	0.0040	0.0040	0.0573	0.1874
9	314.6420	314.6319	-0.0101	0.0006	0.0046	0.0573	0.1874
10	316.6840	316.6768	-0.0072	0.0029	0.0035	0.0573	0.1874
11	318.7240	318.7138	-0.0102	0.0029	0.0029	0.0573	0.1874
12	320.7640	320.7506	-0.0134	0.0033	0.0062	0.0573	0.1874
13	322.8020	322.7876	-0.0144	0.0010	0.0043	0.0556	0.1874
14	324.8390	324.8223	-0.0167	0.0023	0.0033	0.0487	0.1874
15	326.8750	326.8645	-0.0105	0.0062	0.0062	0.0374	0.1874
16	328.9090	328.8995	-0.0095	0.0011	0.0072	0.0373	0.1874
17	330.9430	330.9336	-0.0094	0.0001	0.0011	0.0369	0.1874
18	332.9760	332.9693	-0.0067	0.0027	0.0028	0.0318	0.1874
19	335.0020	335.0001	-0.0019	0.0048	0.0075	0.0366	0.1874
20	337.0100	337.0097	-0.0003	0.0016	0.0064	0.0164	0.1874
21	338.9820	338.9831	0.0011	0.0014	0.0030	0.0178	0.1874
22	340.9050	340.9033	-0.0017	0.0028	0.0028	0.0178	0.1874
23	342.7760	342.7719	-0.0041	0.0024	0.0052	0.0178	0.1874
24	344.5940	344.5886	-0.0054	0.0012	0.0036	0.0178	0.1874
25	346.3590	346.3527	-0.0063	0.0009	0.0022	0.0178	0.1874
26	348.0710	348.0566	-0.0144	0.0081	0.0090	0.0178	0.1874

Fig. 10 Analysis results of the measurement data

Acknowledgements

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