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Sub Title	
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Publisher	慶應義塾大学藤原記念工学部
Publication year	1952
Jtitle	Proceedings of the Fujihara Memorial Faculty of Engineering Keio University Vol.5, No.16 (1952.) ,p.13(13)- 18(18)
JaLC DOI	
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Notes	
Genre	Departmental Bulletin Paper
URL	https://koara.lib.keio.ac.jp/xoonips/modules/xoonips/detail.php?koara_id=KO50001004-00050016-0013

New Application of Vee Block Method in Measurements of Out-of-Roundness for Cylindrical Work

(Received Nov. 5, 1952)

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Abstract

In this paper, it is shown that, indicators placed vertically to vee block do not show up true form in some order of polygons, but using inclined vee block, we can find various orders of polygons or out-of-roundness for a lobed cylinder.

I. Introduction

A centreless grinder or lapping machine will often produce work which is of uniform diameter, but is far from round, so called "Gleichdick"[1]. By "diameter" is meant a dimension as measured between parallel faces, such as those of micrometer (two-point measurement). In actual metal, such a polygon may be only a few thousandths of a millimeter or smaller in size, thus making the lobing invisible, either to the eye or the snap gauge.

Generally lobing on centreless ground work can readily be detected by rotation in a vee block under a comparator (three-point measurement). However, as certain angles of vee will mask the lobing on pentagonal or higher order polygons, two or three tests must be made in vee blocks with different angles,[2] for example 90°, 120° and 150° vee block.

The present author has discovered that it is possible to detect various order polygons or out-of-roundness for cylindrical work by using one vee block at one inclination.

II. Theoretical analysis

In reference to Fig. 1·a, we may express a sectional profile of a cylinder by Fourier's series in tangential polar co-ordinate as follows:

$$r(\theta) = a_0 + \sum_{i=1}^{\infty} C_i \cos(i\theta + \varphi_i) \qquad (1)$$

In the above equation, a_0, C_i and φ_i may be determined by harmonic analysis. If there are no even values of i, we cannot detect lobing by two-point measurement, since $r(\theta) + r(\theta+180^\circ) = 2a_0$.

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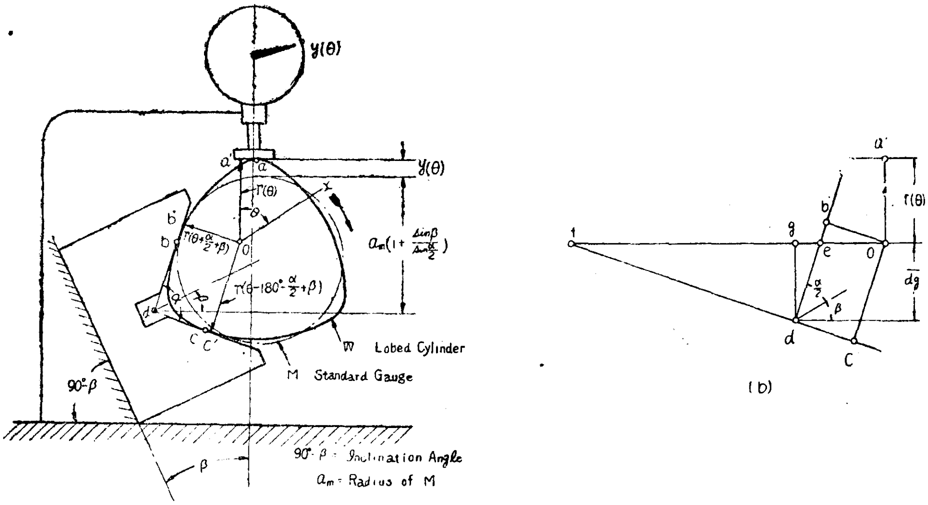
1) E. Sachsenberg u. R. Kreher, Werkstattstech. u. Werksl., **33**, **11**, 280 (1939)

2) T. Nakata and A. Yamamoto, Journal of the J. S. of Mech. Engrs., **53**, (775) 159 (1949)



(*a*) Fig. 1.

Now, in reference to Fig. 1 (a) and (b) again, we get the following relations.

$$y(\theta) + a_m\left\{1+\frac{\sin\beta}{\sin(\alpha/2)}\right\} = r(\theta) + \overline{dg} \qquad (2)$$

and

$$\overline{dg}\left\{\cot\left(\frac{\alpha}{2}+\beta\right)+\cot\left(\frac{\alpha}{2}-\beta\right)\right\} = \frac{r(\theta-180^\circ-\alpha/2+\beta)}{\sin(\alpha/2-\beta)} - \frac{r(\theta+\alpha/2+\beta)}{\sin(\alpha/2+\beta)} \qquad (3)$$

Eliminating $\overline{dg}$ from eq. (2) and eq. (3), and putting eq. (1) into this equation, we obtain the solution $y(\theta)$ for arbitrary rotating angle θ of a cylinder in a vee block.

$$y(\theta) = (a_0 - a_m)\left\{1+\frac{\sin\beta}{\sin(\alpha/2)}\right\} + \sum_{i=2}^{\infty} C_i\,\mu_{i,\alpha,\beta}\cos(i\theta+\varphi_i-\delta_{i,\alpha,\beta}) \qquad (4)$$

where,

$$\left.\begin{aligned}
\mu_{i,\alpha,\beta} &= \sqrt{(1+e_{i,\alpha,\beta})^2 + f^2_{i,\alpha,\beta}}\\
e_{i,\alpha,\beta} &= \frac{\sin\beta\cos i(\alpha/2+90^\circ)}{\sin(\alpha/2)}\cos i(\beta-90^\circ)\\
&\quad + \frac{\cos\beta\sin i(\alpha/2+90^\circ)}{\cos(\alpha/2)}\sin i(\beta-90^\circ)\\
f_{i,\alpha,\beta} &= -\frac{\sin\beta\cos i(\alpha/2+90^\circ)}{\sin(\alpha/2)}\sin i(\beta-90^\circ)\\
&\quad + \frac{\cos\beta\sin i(\alpha/2+90^\circ)}{\cos(\alpha/2)}\cos i(\beta-90^\circ)\\
\delta_{i,\alpha,\beta} &= \tan^{-1}\left(\frac{f_{i,\alpha,\beta}}{1+e_{i,\alpha,\beta}}\right)
\end{aligned}\right\} \qquad (5)$$

It is interesting to note that reading $y(\theta)$ of the indicator is whithout relation to excentricity $C_{i=1}$ of provisonaly selected origin. As only certain term for special i-th order is mostly extraordinary larger usually as compared with other terms, $y(\theta)$ may be considered as a record for a wave about the value $(a_0-a_m)\{1+\sin\beta/\sin(\alpha/2)\}$ with an amplitude $\pm C_i\mu_{i,\alpha,\beta}$ and a phase difference $\delta_{i,\alpha,\beta}$.

This magnification $\mu_{i,\alpha,\beta}$ for various inclination β of $\alpha = 90°$ vee block is shown in Table 1.

Table 1. $\mu_{i,\alpha,\beta}$ and $\delta_{i,\alpha,\beta}$ for $\alpha = 90°$

i \ $\beta°$	0	7.5	15	22.5	30	37.5	45	52.5	60	67.5	75	82.5	90
0	1	1.19	1.37	1.53	1.71	1.86	2	2.12	2.23	2.31	2.37	2.40	2.41
	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1.73	1.92	2.06	2.14	2.15	2.10	2	1.84	1.63	1.44	1.23	1.06	1
	54.74	44.82	35.10	25.69	16.55	7.93	0	−7.17	−12.54	−15.47	−15	−9.62	0
3	2	1.93	1.73	1.41	1	0.52	0	0.52	1	1.41	1.73	1.93	2
	0	−15	−30	−45	−60	−75	−90	75	60	45	30	15	0
4	1	0.85	0.88	1.13	1.49	1.80	2	2.05	1.93	1.65	1.20	0.73	0.41
	0	6.20	21.19	27.91	29.34	13.85	0	−15.88	−33.34	−52.57	−73.99	−106.99	−180
5	2	1.93	1.73	1.41	1	0.52	0	0.52	1	1.41	1.73	1.93	2
	0	−15	−30	−45	−60	−75	−90	75	60	45	30	15	0
6	1.73	0.99	0.37	0.93	1.58	1.96	2	1.72	1.23	0.73	0.63	0.88	1
	−54.74	−89.51	−180	85.50	50.77	23.86	0	−20.73	−35.26	−31.71	0	8.54	0
7	0	1	1.73	2	1.73	1	0	1	1.73	2	1.73	1	0
	90	60	30	0	−30	−60	−90	60	30	0	−30	−60	−90
8	1	1.10	0.88	0.47	0.89	1.61	2	1.84	1.13	0	1.21	2.09	2.41
	0	−8.32	−21.20	0	43.44	27.53	0	−31.90	−69.92	0	73.76	35.52	0
9	0	1	1.73	2	1.73	1	0	1	1.73	2	1.73	1	0
	90	60	30	0	−30	−60	−90	60	30	0	−30	−60	−90
10	1.73	2.38	2.06	0.93	0.62	1.69	2	1.48	0.53	0.73	1.23	1.18	1
	54.74	8.76	−35.10	−85.51	95.65	40.03	0	−34.22	−42.36	31.79	15	−2.32	0
11	2	1.41	0	1.41	2	1.41	0	1.41	2	1.41	0	1.41	2
	0	−45	0	45	0	−45	0	45	0	−45	0	45	0
12	1	1.02	1.37	1.13	0.29	1.32	2	1.50	0.23	1.65	2.34	1.73	0.41
	0	10.46	0	−27.91	0	40.73	0	−48.29	0	52.57	0	54.50	−180

Note: Under numerals in each column is $\delta_{i,\alpha,\beta}$ in degree.

Take, as applications of this theory, the usual measurement in a horizontal vee block $(90°-\beta=0)$, the external measurement by a riding gauge $(90°-\beta=180°)$ and the internal measurement by a cylinder gauge $(90°-\beta=0$ and $\alpha=180°-\alpha'$, where α' is angle between two rigid feet), we then have

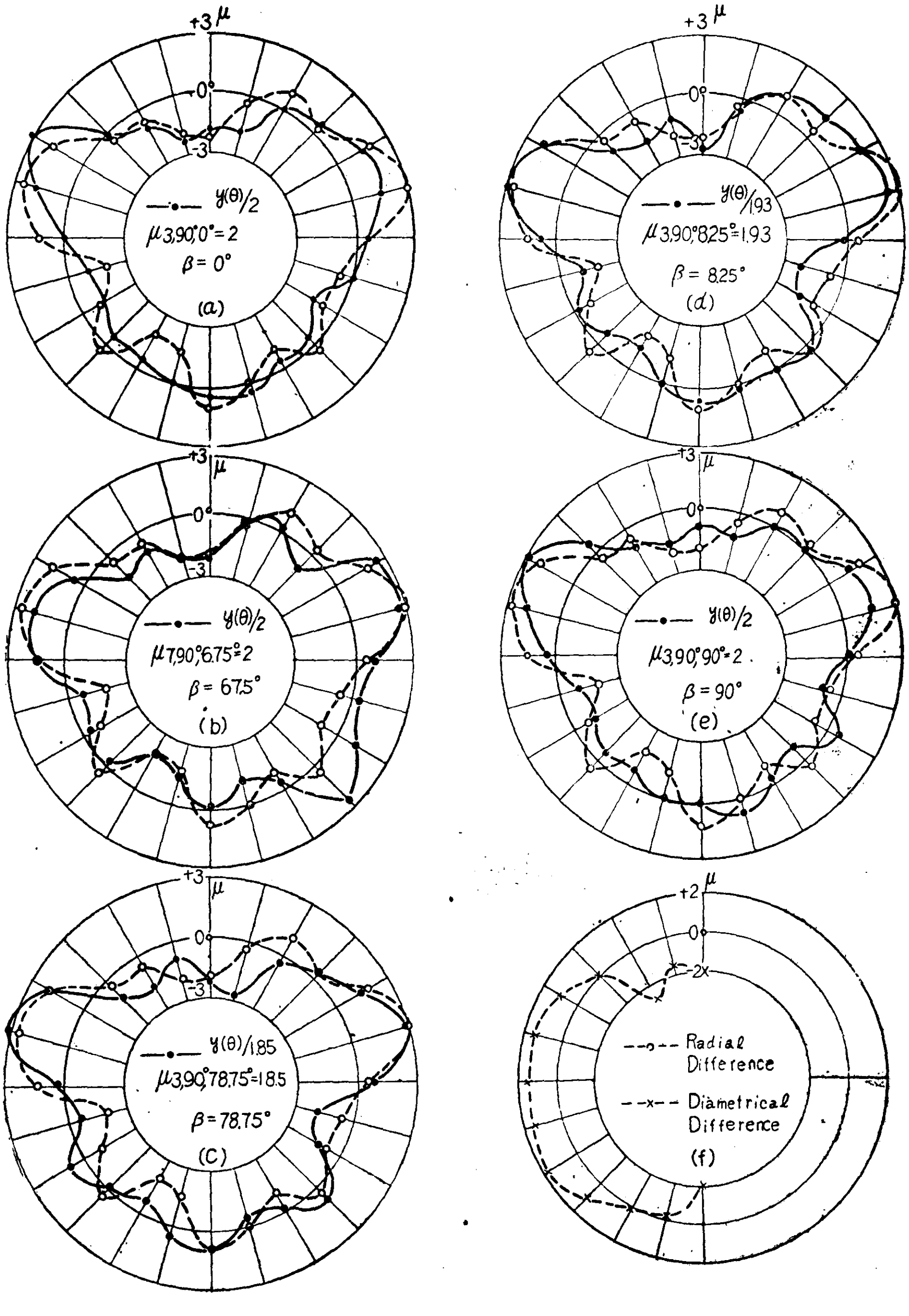

(a)
y(θ)/2
μ3,90°,0° = 2
β = 0°
(b)
y(θ)/2
μ7,90°,6.75° ≒ 2
β = 67.5°
(c)
y(θ)/1.85
μ3,90°,78.75° ≒ 1.85
β = 78.75°
(d)
y(θ)/1.93
μ3,90°,8.25° ≒ 1.93
β = 8.25°
(e)
y(θ)/2
μ3,90°,90° = 2
β = 90°
(f)
Radial Difference
Diametrical Difference

Fig. 2

$$y(\theta) = (a_0 - a_m)\left\{1 + \frac{1}{\sin(\alpha/2)}\right\} + \sum_{i=2}^{\infty} C_i\, \mu_{i,\alpha,90^\circ} \cos(i\theta + \varphi_i)$$

where $\mu_{i,\alpha,90^\circ} = 1 + \dfrac{\cos i(\alpha/2 + 90^\circ)}{\sin(\alpha/2)}$ (6)

$$y(\theta) = (a_0 - a_m)\left\{1 - \frac{1}{\sin(\alpha/2)}\right\} + \sum_{i=2}^{\infty} C_i\, \mu_{i,\alpha,-90^\circ} \cos(i\theta + \varphi_i)$$

where $\mu_{i,\alpha,-90^\circ} = 1 - \dfrac{\cos i(\alpha/2+90^\circ)}{\sin(\alpha/2)}$ (7)

and $y(\theta) = (a_0 - a_m)\left\{1 + \dfrac{1}{\cos(\alpha'/2)}\right\} + \sum_{i=2}^{\infty} C_i\, \mu_{i,\alpha',90^\circ} \cos(i\theta + \varphi_i)$

where $\mu_{i,\alpha',90^\circ} = 1 + \dfrac{\cos i(180^\circ - \alpha'/2)}{\cos(\alpha'/2)}$ (8)

respectively.

III. Experimental example

The author has measured the out-of-roundness of a dissipated somewhat piston pin (19 mm. $\phi \times 54$ mm.), in which $\alpha = 90^\circ$ vee block was used in various inclination, namely $\beta = 0^\circ$, 67.5°, 78.75°, 82.5° and 90°. In this test I made use of Orthotest (Seiki), and Optimeter (Zeiss) only for $\beta = 0^\circ$.

In Fig. 2 (a), (b), (c), (d), (e), (f) records of the out-of-roundness divided by the magnification of lobing, which is the largest of the orders judged from reading, are shown with its diametrical difference and absolute out-of-roundness measured between centres. Fig. 3 records spectrum C_i ($i = 2, 3, \ldots\ldots, 12$).

Also Fig. 4 shows out-of-roundness for spring steel cylinder (30 mm. $\phi \times$ 100 mm.) ground by centreless grinder. This is considered to be "Gleichdick" obviously.

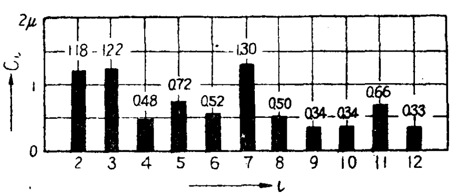


Fig. 3

From these figures, it is noted that the measurement by a vee block at $\beta = 82.5^\circ$ is superior to the usual measurement in a horizontal vee block, and it is considered to approximately coincide with the absolute measurement.

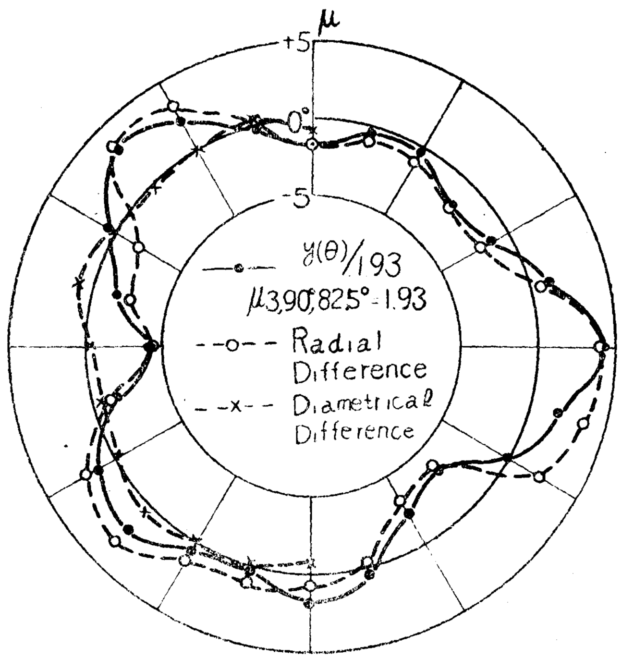

μ
+5
0°
-5
y(θ)/1.93
μ3,90,825°=1.93
Radial Difference
Diametrical Difference

Fig. 4