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# BASIC CHARACTERISTIC OF LINEAR DISPLACEMENT SENSOR USING MEANDER COIL AND PATTERN GUIDE

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***ABSTRAK :*** *Pengesan kedudukan linear digunakan untuk mengesan kedudukan sebenar objek bergerak dalam Linear DC Motor (LDM). Ketepatan pengesanan adalah sangat penting untuk memastikan operasi proses pengeluaran berjalan lancar. Dalam kertas ini, pengesan kedudukan berasaskan konsep induktif telah dihasilkan. Ia terdiri daripada mata pengesan dan corak penunjuk. Kombinasi mata pengesan dan corak penunjuk sangat penting untuk kejituan bagi kedudukan. Mata pengesan diperbuat daripada bahan tembaga manakala pattern guide diperbuat daripada besi lembut 'SS400'. Kesan kedudukan penunjuk kepada voltan keluaran untuk frekuensi masukan dan voltan terjahan yang pelbagai diperhatikan dan diterangkan dalam kertas ini. Daripada keputusan yang diperolehi, voltan keluaran meningkat apabila frekuensi masukan dan voltan terjahan meningkat.*

**ABSTRACT :** Linear displacement sensor is used to detect the actual displacement of the moving objects in the Linear DC Motor (LDM) (Wakiwaka *et al,* 1996). The accuracy of the detection is very important to make sure the production process operate properly. The displacement sensor based on the inductive concepts has been developed. It is composed of the sensor head and pattern guide. The combination of the sensor head and pattern guide is important to get the high accuracy of the positioning. Sensor head is made from copper material while pattern guide is made from soft iron SS400. The displacement of pattern effects to the output voltage for various input frequency and exciting voltage has been observed and discussed in this paper. From the results obtained, output voltage increases as the input frequency and exciting voltage increases. In term of hysteresis and linearity, input frequency 20kHz and exciting voltage 1.0 volt is the best performance of sensor.

**KEYWORDS :** Linear displacement sensor, displacement, accuracy, inductive, sensor head, pattern guide, output voltage, input frequency, exciting voltage, hysteresis, linearity.

## INTRODUCTION

In the modern industrial production processes the actual displacement of fast moving objects needs to be detected, this is ideally done without mechanical contact. For this there exists a variety of suitable sensors that provide an output signal (voltage or current) proportional to the displacement of target and sensor. In industrial usage there are exactly defined requirements for reliability, ruggedness, measuring range etc (Jagiella *et al,* 2002). Likewise, electrical parameters such as supply voltage range, output signal and EMC requirements are firmly defined in norms and standard (Kacprzak *et al,* 2001). To find the best sensor for the displacement purpose, accuracy is an important factor to be considered. Although the laser sensor is widely used in the modern industry, in terms of the accuracy it is less accurate if any obstacle exists in between the detection objects. It is also not suitable for the harsh environment. Optical sensor is also useful when high accuracy measurement is required, but it is unsuitable for harsh environment and is also expensive (Hristoforou and Reilly, 1994). To overcome this problem, the linear displacement sensor has been proposed. It is insensitive to environmental influences such as oil, dirt, water and electromagnetic field.

This linear displacement sensor is composed of sensor head and pattern guide. In this research, the meander coil based on copper has been proposed as a sensor head. This sensor head consists of exciting coil, *Ec* and search coil, *Sc*. It is made by thin negative photoresist PCB. The material soft iron SS400 was used to make the pattern guide. The function of the sensor head is to produce the electrical signal by the magnetic field, and pattern guide is to allocate the position of the sensor head. The best combination of the sensor head and pattern guide is important to get high accuracy of the positioning. Basically, the linear displacement sensor based on the inductive concepts has been developed. The conversion of the mechanical measured into primary electrical information takes place through two superposed effects; inducing magnetic flux into the pattern and changing inductance of the sensor coil (Zhang *et al,* 2006). In this paper, a set of experiments has been done to observe the effects of the various input frequency and the exciting voltage to the output voltage. The input frequency varies by set of 10 kHz, 20 kHz, 30 kHz, 40 kHz, 60 kHz, 80 kHz and 100 kHz. From the results, it has been shown that output voltage increases as the input frequency increased, but from input frequency 80 kHz and 100 kHz the increases of the output voltage is slowed down. Exciting voltage has been set by 0.1 volt, 0.2 volt, 0.5 volt, 0.7 volt and 1 volt. The result shows that output voltage increases proportionally to increasing exciting voltage. In terms of hysteresis and linearity, input frequency at 20 kHz and exciting voltage at 1V is the best condition for the operation of linear displacement sensor. Compared with other linear displacement sensors, the linearity and hysteresis of this sensor is higher. Kano *et. al* (1990) proposed linear position detector with rod shape electromagnet with hysteresis 0.35% and linearity 0.3%. But in terms of size, the linear displacement sensor proposed is small and has a simple structure compared to the linear position detector. Thus, the overall cost will be reduced. The linearity and hysteresis of the linear displacement sensor can be improved by using signal processing circuit.

## STRUCTURE OF THE LINEAR DISPLACEMENT SENSOR

The proposed linear displacement sensor consists of two parts, sensor head and pattern guide (Figure 1). Sensor head consists of exciting coil, $E_C$ and search coil, $S_C$ (Figure 2). The sensor head has been designed with external dimension 10mm x 20mm with 14 turns of meander coil. The gap between exciting coil-exciting coil ($G_{ee}$) and search coil-search coil ($G_{ss}$) were designed with gap 0.7mm and gap between $E_C$ and $S_C$ ($G_{es}$) is 0.2mm. Exciting coil, $E_C$ is supplied with alternating current and input frequency for certain range while search coil, $S_C$ which is used to detect an output voltage is based on the variations of the magnetic flux between sensor head and pattern. Pattern guide is to allocate the position of sensor head and it enables the sensor head to move along the pattern with constant gap during the detection of the displacement.

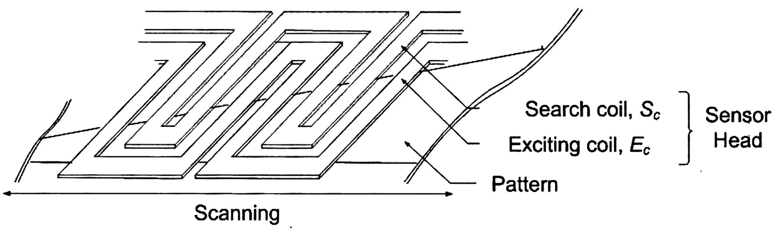
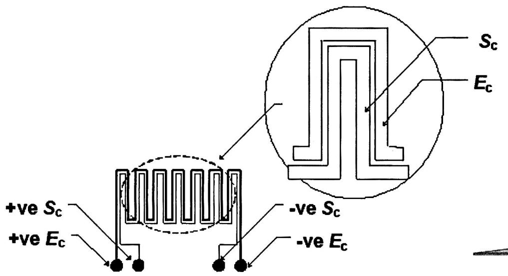



**Figure 1.** *Structure of the Linear Displacement Sensor*



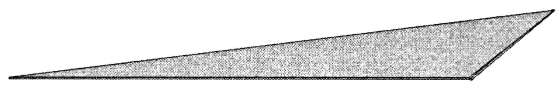



**Figure 2(a).** *Structure of the Sensor Head* **Figure 2(b).** *Structure of the pattern*

The inspection of linear displacement sensor is done by moving the sensor head along the pattern with constant gap. The exciting coil of the sensor head was excited by alternating current sine waves with a certain input frequency. The magnetic flux generated by the $E_C$ will induce magnetic flux on the pattern surface. Intensity distribution of induced magnetic flux on the pattern is inversely dependent on the coil-to-pattern displacement, meaning that when the displacement of the pattern increased, the induced voltage will be decreased. At the same time, this magnetic flux in the pattern will generate the secondary magnetic flux that is partly linked by the coil turns; thus, it will induce the secondary voltage in the search coil as output voltage, $V_{SC}$. The amount of the induced voltage on the search coil is inversely dependent on the coil-to-pattern displacement as well. The inspection of the linear displacement sensor was focused on the effects of the displacement of pattern to the output voltage for various input frequency and exciting voltage.

## BASIC PRINCIPLES OF LINEAR DISPLACEMENT SENSOR

Linear displacement sensor based on the inductive concepts had been developed. Its principles are based on Faraday's Law induction; which states that a moving magnetic field induces a voltage in an electrical conductor proportional to the rate change of magnetic flux. If rate change of magnetic flux is in Wb/sec, the induced voltage will be in volts. If varying magnetic flux is applied to a coil with $N$ number of turns, with the same cross-section area, the flux through each turn will be the same, and the induced voltage is

$$V = -N\frac{d\phi}{dt} = -N\frac{d(BA)}{dt} \tag{1}$$

Where, $V$ is induced electromotive force in volts, $N$ is the number of turns of the coil, $d\phi/dt$ is the rate change in magnetic flux (Webers/sec), $B$ is magnetic field in Tesla, and $A$ is cross sectional area of the pattern facing the sensor coil (m$^2$). Induced voltage depends on moving the source of the magnetic field, varying the current in the coil, changing the orientation of the magnetic source with respect to the pick-up-circuit and changing the geometry of a pick-up-circuit, for instance, by stretching it or squeezing or changing the number of turn in a coil. By considering a motion sensor, the flux enclosed by the loop is

$$\phi_B = BA \tag{2}$$

$$A = \tfrac{1}{2}\,(a+b)\,l \tag{3}$$

Where $A$ is the cross sectional area pattern facing the sensor coil, as shown in Figure 3. The voltage induced in the $S_C$ can be found from Faraday's Law;

$$V = -N\frac{d\phi}{dt} = -N\frac{d}{dt}(BA) = -NB\frac{dA}{dt} \tag{4}$$

The output voltage is a linear function of rate of change of a sensor movement. When the sensor head moves along the pattern guide, the output voltage induced in the $S_C$ depend on the area of the pattern facing the sensor coil. The wider the area of pattern facing the sensor coil, the greater the total flux lines cutting the pattern area and the greater the induced output voltage; compared to narrow area of pattern (Figures 4a and 4b). Output voltage induced in the $S_C$ is proportional to the area of pattern facing the sensor coil. Once displacement of pattern increases, the area of pattern facing sensor coil decreases and thus induced output voltage will decrease as well.

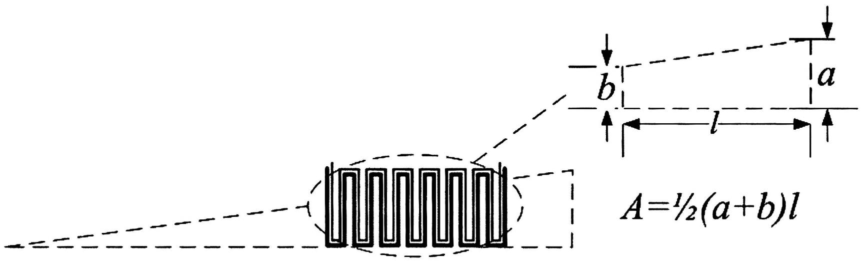
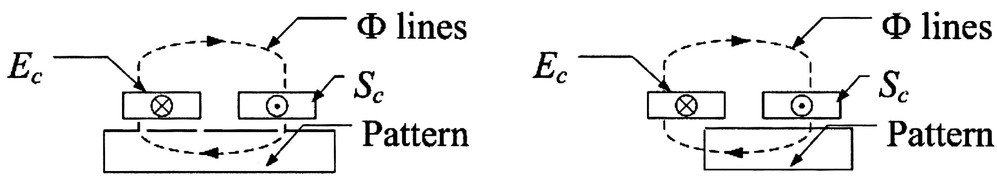



**Figure 3.** *Area of the pattern facing the sensor coil*




(a) Pattern with narrow surface area (b) Pattern with wider surface area

**Figure 4.** *Induced magnetic field, $E_c$ on the pattern*

The output voltage induced in the $S_C$ also depends on the inductance, *L* of the coil. From the equation;

$$n\phi_B = Li \qquad (5)$$

By substituting equation (5) into equation (4), it becomes:

$$V = -N\frac{d\phi_B}{dt} = -L\frac{di}{dt} = -N\frac{dA}{dt} \qquad (6)$$

Equation (6) shows that the output voltage is proportional to the rate change of current, *di/dt* and rate of change of area, *dA/dt*.

The inductance of a coil is affected by two factors; the number of turns in the coil and the area of the cross section of the coil. High number of turns in a coil will produce higher inductance. This is true because the more turns there are in a coil, the greater the numbers of magnetic field interactions. This is similar to the cross sectional area of a coil. It will produce high inductance whenever the area increased. This factor is closely related to the number of turns in a coil. It includes consideration of the spacing of the turns. Since a magnetic field becomes weaker as it moves out, turns that are closely spaced provide for interactions where the fields are strongest.

## MEASUREMENT OF LINEAR DISPLACEMENT SENSOR

The inspection of linear displacement sensor has been done by supplying the sensor with an alternating current signal sine wave at certain input frequency and exciting voltage. Figure 5 shows the whole system of the Linear Displacement Sensor. Power amplifier is needed to supply the power to the sensor, this is done because function generator can only provide the signal and vary the frequency. The output signal from the sensor is too small and their magnitude is in order of millivolts. On the other hand, standard electronic data processing, such as A/D converters, frequency modulators and data recorders require input signal of sizeable magnitudes- in the order of volts. Therefore, an amplification of the sensor output signal has to make with a voltage gain up to 2000. The output voltage has been displayed on the oscilloscope, and the data has been captured in Figure 7.

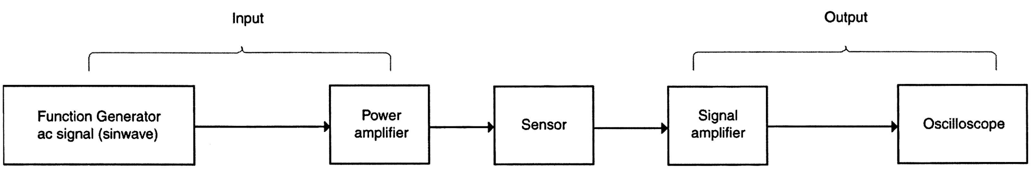



***Figure 5.*** *Block diagram of Linear Displacement Sensor*

The experimental setup for the linear displacement sensor is shown in Figure 6. Output voltage induced in the search coil is based on the surface area of the pattern facing the sensor head. When the displacement of the pattern increased, the surface area of the pattern facing the sensor head will become smaller, therefore the magnetic flux induced in the pattern will decrease proportionally as the displacement of the pattern increase. At the same time, the output voltage induced in the search coil, $S_C$ also decreased and the displacement of the pattern increased.

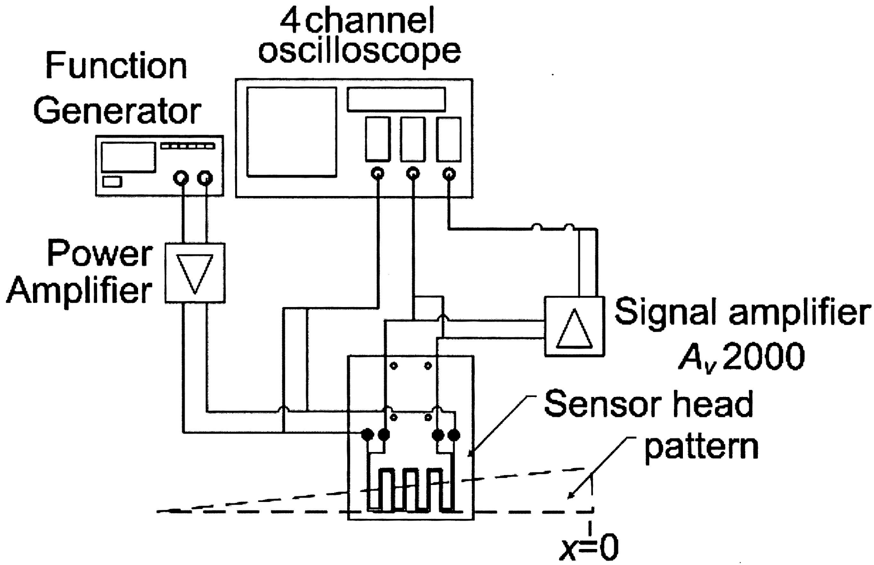



***Figure 6.*** *Experiment setup for performance study*

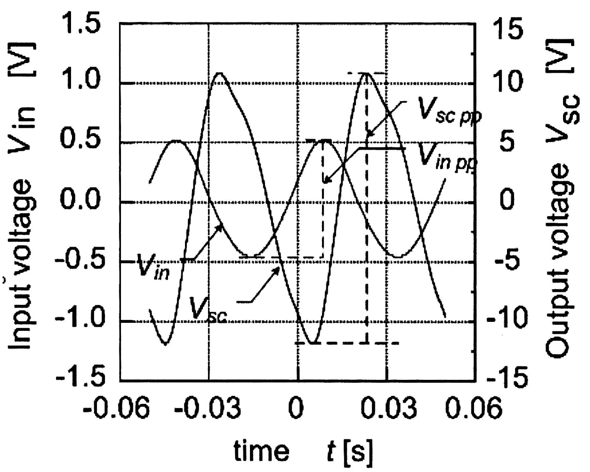



***Figure 7.*** *Output voltage*

The inspection of the linear displacement sensor started with an observation on the effect of displacement of the pattern to the output voltage by varying the input frequency and fixed exciting voltage at 1volt. Seven sets of different input frequency were used in the experiments ranging from 10 kHz to 100 kHz. The results are shown in Figure 8. The inspection continued with an observation on the effects of displacement of the pattern to the output voltage by varying the exciting voltage and fixed input frequency at 20 kHz. Five sets of different exciting voltages were used in the experiments ranging from 0.1V to 1.0V.

## CHARACTERISTIC OF THE OUTPUT VOLTAGE

### *(i) Effects of the various input frequency*

The results show that the output voltage decreased as the displacement of pattern increased as explained in the basic principles. By varying the input frequency, the output voltage increased as the input frequency increased (Figure 8). This is based on the formula $V_{out}=d\phi/dt$, when the frequency increase, time will decrease and $d\phi/dt$ will increase. As a result $V_{out}$ will increase as the input frequency increase. For frequency 10 kHz, 20 kHz, 30 kHz, 40 kHz, and 60 kHz the output voltage increased linearly by increasing the input frequency. But for input frequency 80 kHz and 100 kHz, the increase of the output voltage is saturated. This is because of the eddy current effect. The characteristic of output voltage by varying the input frequency has been analyzed in terms of the hysteresis and linearity. Supposedly, the hysteresis and linearity will increase as the input frequency increase. But in Figure 9, the results of hysteresis and linearity for output voltage are not stable. The hysteresis of output voltage for input frequency 10 kHz is high compared with the input frequency 20 kHz and 30 kHz. For input frequency 10 kHz the hysteresis is 2% and linearity is 4%, but for 20 kHz and 30 kHz the hysteresis is 1.8% and linearity is 2.5%. From frequency 40 kHz to 100 kHz the hysteresis of the output voltage increased from 2.5% to 3%, and linearity increased from 3.2% to 6.2%. The results show that frequency 20 kHz and 30 kHz is the best input frequency for linear displacement sensor in terms of hysteresis and linearity.

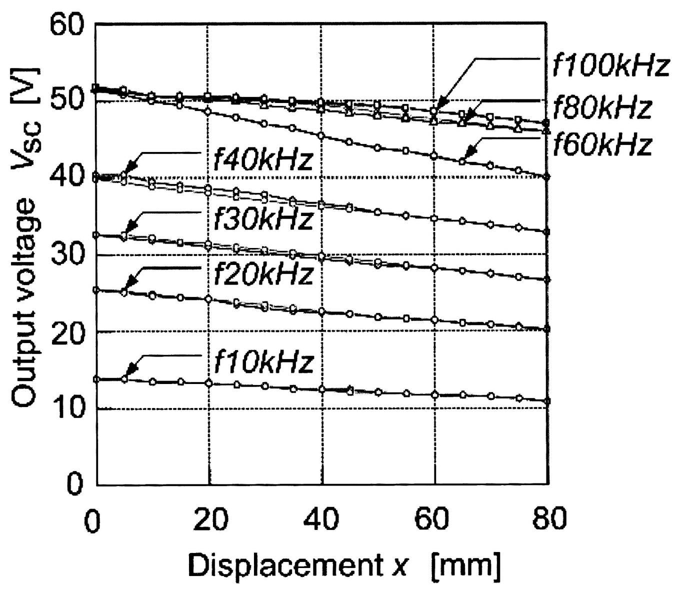



***Figure 8.*** *Output voltage versus displacement with different input frequency ($V_{ex}$ : 1 V)*

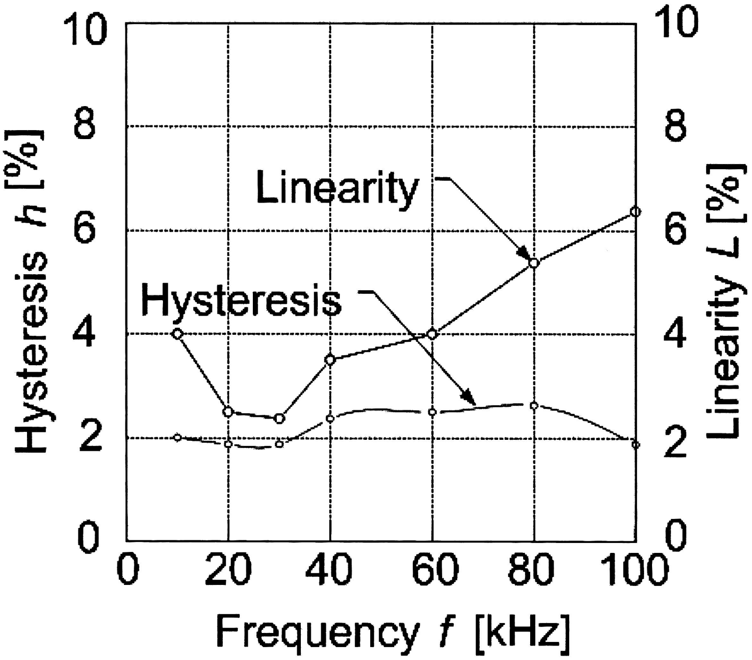



**Figure 9.** *Hysteresis, Linearity versus Frequency ($V_{ex}$ : 1V)*

*(ii) Effects of the various exciting voltage*

By varying the exciting voltage, the output voltage increased as the exciting voltage increased (Figure 10). The results show that, for exciting voltage at 0.1V and 0.2V the changes of the output voltage is about 1V. Exciting voltage at 1.0V gives the higher changes of the output voltage with approximately 3V. The changes of output voltage for the exciting voltage at 0.5V and 0.7V are approximately 2V. The characteristic of output voltage by varying the exciting voltage has been analyzed in terms of the hysteresis and linearity. The results show that the hysteresis and linearity decrease as the exciting voltage increase to certain limits. Exciting voltage at 0.1V gives higher hysteresis and linearity with 11% of hysteresis and 14.8% of linearity. For exciting voltage from 0.2V to 1V, the hysteresis is maintained about 2% and linearity decreases from 5.2% to 4%. From the results, the best operation of the linear displacement sensor is with exciting voltage 1V, where the output voltage is at the lowest hysteresis and linearity. In this experiment, the maximum exciting voltage that has been considered is 1V. This is because, when linear displacement sensor operates with exciting voltage higher than 1V, it will heat up and burn the sensor coil.

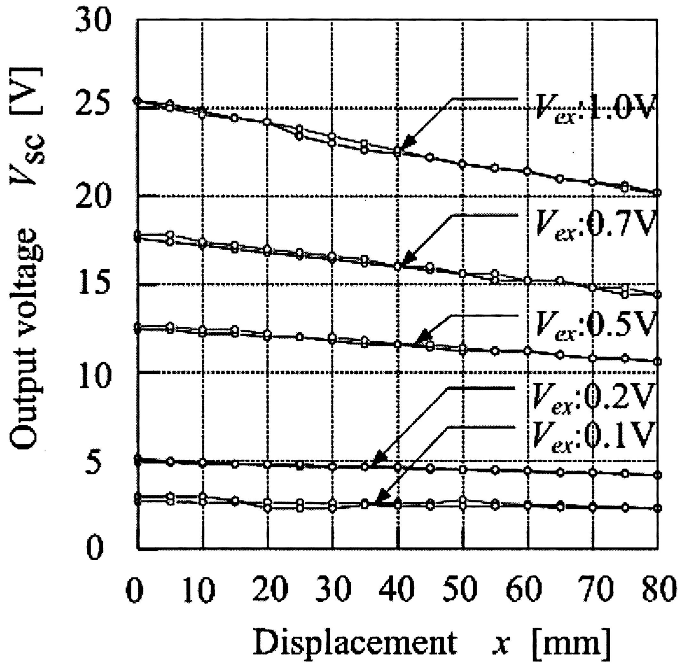



**Figure 10.** *Output voltage versus displacement with different exciting voltage ( $F_{in}$ : 20kHz)*

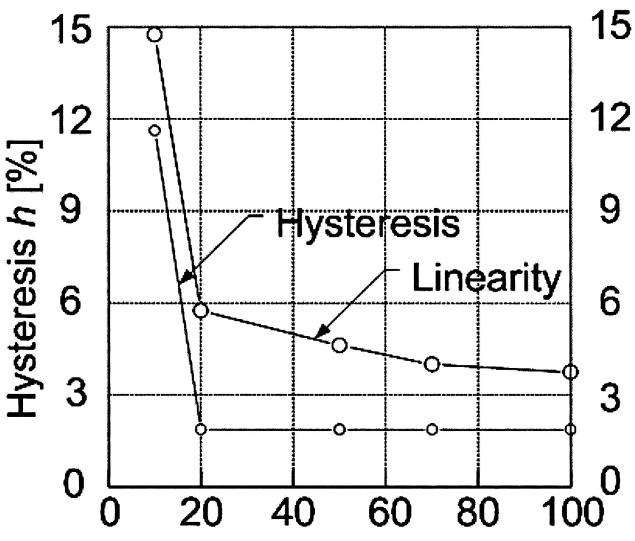



**Figure 11.** *Hysteresis, Frequency versus Exciting voltage ( $F_{in}$ : 20kHz)*

## CONCLUSION

The structure and basic principles of the linear displacement sensor has been explained. The functionality of the sensor and the effects of the displacement of the pattern to the output voltage have been observed. Results show that linear displacement sensor was function as their principles, where output voltage increases as the displacement of the pattern decreases. The characteristic of the output voltage by varying the input frequency and exciting voltage has been analyzed. By varying the input frequency, output voltage was proportionally increased as the input frequency increased. In terms of hysteresis and linearity, the best operation of the linear displacement sensor is with input frequency 20 kHz. By varying the exciting voltage, output voltage also increases as the exciting voltage increases. From analysis of hysteresis and linearity, the best operation of linear displacement sensor is with exciting voltage at 1V. It can be concluded that the best condition for operation of the linear displacement sensor developed is with input frequency at 20 kHz and exciting voltage at 1V.

## REFERENCES

Hristoforou, E and Reilly, R.E. (1994). Displacement sensors using soft magnetostrictive alloys, IEEE Trans. Magnetics, **30(5)** : pp 2728-2733.

Jagiella, M. , Droxler, S.F. and Dorneich, A. (2002). New magneto-inductive sensing principle and its Implementation in sensors for industrial applications, Proc. IEEE Sensor 2002, Conference1, **11**: pp 771-778.

Kacprzak, D. , Taniguchi, T. , Nakamura, K. , Yamada, S. and Iwahara, M. (2001). Superposition of signal components during inspection of printed circuit boards by an eddy current testing probe with a solenoid pick-up coil, IEEE Trans. Magnetics, **37(4)** : pp 2794 - 2796.

Kano, Y. , Yanase, S. and Nashizawa, M (1996). Linear position detector with rod shape electromagnet, IEEE Trans. Magnetics, **26(5)** : pp 2023-2025.

Wakiwaka, H., Yanase, S. and Nashizawa, M. (1996). Characteristics of meander coil impedance with opened scale coil for linear sensor, IEEE, pp 487-492.

Zhang, G., Chen, Y., Zhou, Z. and Li, S. (2006). Design of an inductive long displacement measurement instrument, Proc 6th World Congress on Intelligent Control and Automation, pp 5098-5101.

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# EVALUATION OF DIFFERENT CUTTING TOOLS WHEN MILLING VANADIS 10

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***RINGKASAN :*** *Artikel ini menerangkan kesan kekerasan logam kerja, kadar pemotongan, kelajuan pemotongan dan kedalaman axial terhadap jangka hayat pemotong dan kekasaran permukaan logam semasa pemesinan Vanadis 10 dengan menggunakan mata pemotong Kennametal KC850 dan K313. Logam Vanadis 10 biasanya digunakan di dalam kilang membuat die dan mould. Methodology sambutan permukaan telah digunakan dalam menjalankan eksperimen. Keputusan jangka hayat dan kekasaran permukaan amat memuaskan. Kekerasan logam kerja dan faktor-faktor lain memainkan peranan yang penting dalam menghasilkan keputusan eksperimen.*

**ABSTRACT :** This paper describes a study on the effects of work piece hardness, feed rate, cutting speed, and axial depth on the output parameters of tool life and surface roughness finishing when machining raw material of Vanadis 10 using KC850 and K313 Kennametal inserts. The Vanadis 10 is widely applied in manufacturing of dies and moulds especially in applications where tooling made from cemented carbide tends to chip off or crack. Statistical analysis method utilizing response surface methodology (RSM) is applied and shows that the effects on tool life and surface finish roughness are statistically significant. The workpiece hardness and other factors played significant roles.

**KEYWORDS :** Workpiece, surface roughness, hardening, Vanadis 10, response surface methodology

## INTRODUCTION

In manufacturing of dies and moulds, many different cutting tools are involved from deep hole drills to the smallest ball nose end mills. The selection of a die and mould material is often made at the design stage in order to have the material ready to be machined when the design is completed. This is not always a simple task. In many cases, the choice of the material grade is a compromise between the wishes of the mould maker and the molders (Sandvic Coromant, 2000). Therefore the researchers of die and mould and manufacturing companies are looking forward to improve the aspects of die and mould machining especially in term of cutting tools materials which relate to machining cost and surface roughness finishing. Some studies deal with the performance of cutting tools like Inconel 718 using turning operations (American N. C. M., 2005). Recent study used milling operation in order to carry out the experiment using Vanadis 10 plate.

Machining of raw material for making dies and moulds can be enhanced by the use of advanced cutting tool materials such as KC850 and K313 with improved physical and mechanical properties (Kennametal, 2004).

Recent study also observed and evaluated the performance of cutting tool materials when machining Vanadis 10 in terms of tool life, surface finish roughness as well as wear mechanisms under various finishing conditions. The tools failed mainly due to the wear on the cutting edges which interacted with work piece. The hardness of the workpiece played a significant role in this failure. High abrasion wear, plastic deformation, and cratering wear were observed on cutting tools especially for KC850. Through observation on the tool wear, factors involved include characteristics of the workpiece; the extremely high abrasive wear resistance, high compressive strength, as well as high hardness create difficulties in machinability and generated high wear values leading to short tool life for cutting tools (Sandvic Coromant. 2000). The cold work tool steel such as Vanadis 10 can be hardened to obtain higher hardness for making cutting tools. As the alloy content and hardness goes up, the machinability goes down. Machining cost needs to be considered as it reached 65% of the total production cost for a die and mould. This meant that machinability is an important factor for economical production of dies and moulds. The relationship between the machining cost and tool life are highly correlative.

## METHOD

Machining of Vanadis 10 is carried out using a CNC vertical milling machine with speeds ranging from 800 rpm to 3000 rpm. Workpiece dimensions are 170mm length, 100mm width, and 20mm thickness. One millimeter thickness of the top surface of workpiece was removed prior to actual machining in order to eliminate any surface defects that can adversely affect machining results. Coated carbide KC850 and uncoated carbide K313 inserts were used for machining (American N. C. M. 2005, Kennametal, 2004). The chemical compositions and physical properties of Vanadis 10 are given in Table 1 and Table 2 respectively.

**Table 1.** Chemical composition of Vanadis 10

| C | Cr | Mo | V |
|---|---|---|---|
| 2.90% | 8.00% | 1.50% | 9.80% |

**Table 2.** Physical properties of Vanadis 10

| Temperature | $20^{\circ}C$ | $200^{\circ}C$ | $400^{\circ}C$ |
|---|---|---|---|
| Density kg/m3 | 7400 | – | – |
| Modulus of elasticity N/mm2 | 220 000 | 210 000 | 220 000 |
| Coefficient of thermal expansion per $^{\circ}C$ from $20^{\circ}C$ | – | 10.7x106 | 11.4x106 |
| Thermal conductivity W/m. $^{\circ}C$ | – | 20 | 22 |
| Specific heat J/kg$^{\circ}C$ | 460 | – | – |

The following coating layers for insert KC850 are specified by the insert manufacturer :

- TiN (outer layer) : 3.0 micron
- TiCN: 3.5 micron
- Tic (inner layer) : 4.5 micron
- Total 11 micron

In this study, the cutting conditions employed during the end milling of Vanadis 10 are shown in Table 3.

**Table 3.** Cutting parameters

| | |
|---|---|
| Speed (m/min) | 80, 190, 300 |
| Feed rate (mm/rev.) | 0.025 – 0.05 |
| Axial depth (mm) | 0.05, 0.1, 0.15 |
| Radial depth (mm) | 3.5 |

Cutting conditions, cutting speeds, feed rate, and axial depth as shown in Table 3 can be applied for finish machining of Vanadis 10 in the manufacturing processes. Cutting forces generated during the machining trials were measured using dynamometer. Tool wear was measured with a microscope connected to a digital readout at a magnification of 5x. Surface roughness was measured using a hand held roughness tester TR200. Statistical method using RMS can assist to obtain and create predicted values for cutting speed, feed rate, and axial depth. The RSM is able to determine and quantify the relationship between the values of one or more measurable response variables and set up a group of experimental factors presumed to affect the responses, in order to find the experimental factors that produce the best value or best set of values of the response. This experiment applied three variable factors of the experimental machining data shown in Table 4. The cutting tools of KC850 and K313 are used and recommended by Montgomery, D. C. (1997) and Khuri *et. al.* (1996).

**Table 4.** Experimental machining data

| C1 | C2 | C3 | C4 | C5 (m/min) | C6 (mm/rev) | C7 (mm) |
|---|---|---|---|---|---|---|
| 3 | 1 | 2 | 1 | 80 | 0.0500 | 0.10 |
| 12 | 2 | 2 | 1 | 190 | 0.0500 | 0.15 |
| 14 | 3 | 0 | 1 | 190 | 0.0375 | 0.10 |
| 7 | 4 | 2 | 1 | 80 | 0.0375 | 0.15 |
| 17 | 5 | 0 | 1 | 190 | 0.0375 | 0.10 |
| 2 | 6 | 2 | 1 | 300 | 0.0250 | 0.10 |
| 5 | 7 | 2 | 1 | 80 | 0.0375 | 0.05 |
| 4 | 8 | 2 | 1 | 300 | 0.0500 | 0.10 |
| 11 | 9 | 2 | 1 | 190 | 0.0250 | 0.15 |
| 6 | 10 | 2 | 1 | 300 | 0.0375 | 0.05 |
| 10 | 11 | 2 | 1 | 190 | 0.0500 | 0.05 |
| 13 | 12 | 0 | 1 | 190 | 0.0375 | 0.10 |
| 9 | 13 | 2 | 1 | 190 | 0.0250 | 0.05 |
| 15 | 14 | 0 | 1 | 190 | 0.0375 | 0.10 |
| 1 | 15 | 2 | 1 | 80 | 0.0250 | 0.10 |
| 8 | 16 | 2 | 1 | 300 | 0.0375 | 0.15 |
| 16 | 17 | 0 | 1 | 190 | 0.0375 | 0.10 |

[C1 = Standard order, C2 = Run order No., C3 = Stores the point type,
C4 = Block No., C5 = Cutting speed m/min, C6 = Feed rate mm/rev,
C7 = Axial depth mm].

## RESULTS AND DISCUSSION

Figures 1, 2, and 3 described the tool life generated when machining Vanadis 10 with KC850 and K313 tools at various cutting conditions. The K313 uncoated cutting tool produced the best overall performance in terms of tool life whereas, wear crater, plastic deformation and abrasive flank wear compared to KC850 coated cutting tool. The KC850 and K313 have different chemical compositions, physical properties, and percentage of tungsten carbide, cobalt, and hardness of cutting edge of cutting tools. The K313 should theoretically perform better than KC850 because of its higher hardness, higher tungsten carbide and cobalt. Experimental results confirmed the theoretical performance of K313. The KC850 is subjected to machining conditions of cutting speed 300m/min, feed rate 0.05mm/rev., and axial depth 0.1mm. A crater wear, abrasive flank wear, and plastic deformation appeared on cutting edge as shown in Figure 4. This consequently resulted in accelerated short tool life Serope (1995). Tool K313 is subjected to machining conditions of cutting speed 300 m/min, feed rate 0.05mm/rev., and axial depth 0.1mm as shown in Figure 5. Abrasive flank wear, chipping and crater wear were obtained without plastic deformation. The wear observed on tool K313 is the same as for KC850 at the same machining conditions. Tool life decreased rapidly with increasing temperature. This depends on the energy generated per unit time and the cutting speed and hardness of the workpiece material. Therefore when machining of any raw material, cutting speeds and feed rate will automatically decrease with increasing hardness (Kennametal cutting tools, 2004, Schey, 2002, Beitzand & Kuttner, 1994).

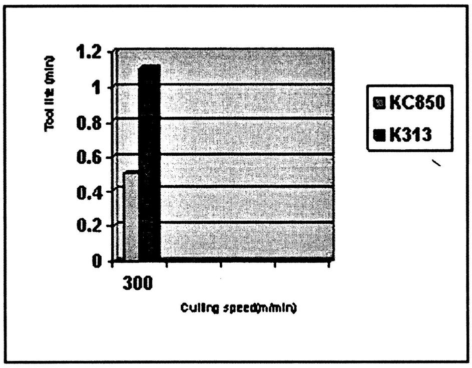


*Figure 1.* *Lower tool life obtained for K313 when machining Vanadis10 at feed rate 0.05 mm/rev and cutting speed 300m/min*

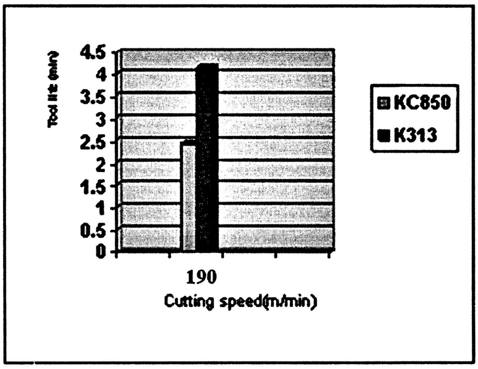


*Figure 2.* *Moderate tool life obtained for K313 when machining Vanadis10 at feed rate 0.05 mm/rev and cutting speed 190m/min*

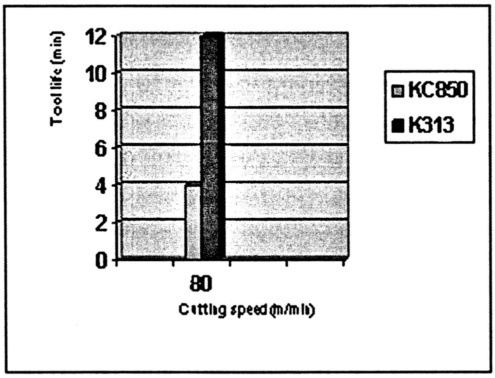


**Figure 3.** *Higher tool life obtained for K313 when machining Vanadis 10 at feed rate 0.05 mm/rev and cutting speed 80 m/min*

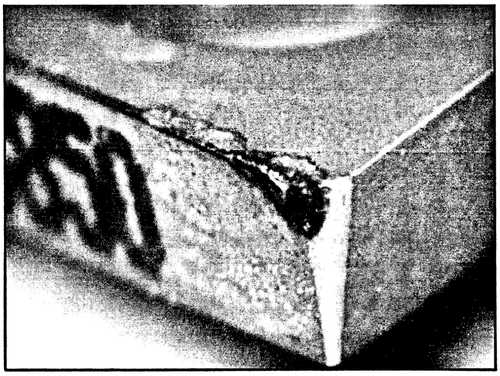

**Figure 4.** *Wear generated after machining Vanadis 10 with KC850 at feed rate 0.05 mm/rev and cutting speed 300m/min and axial depth 0.1mm*

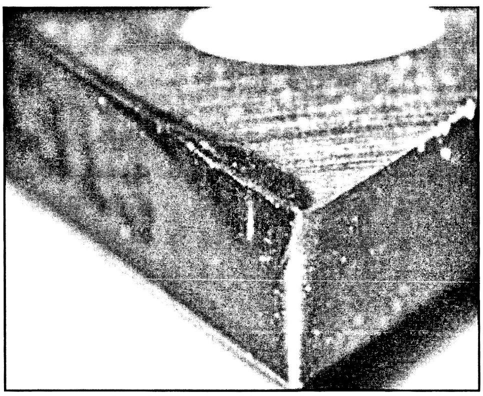

**Figure 5.** *Wear generated after machining Vanadis 10 with KC313 at feed rate 0.05 mm/rev, cutting speed 300m/min and axial depth 0.1mm*

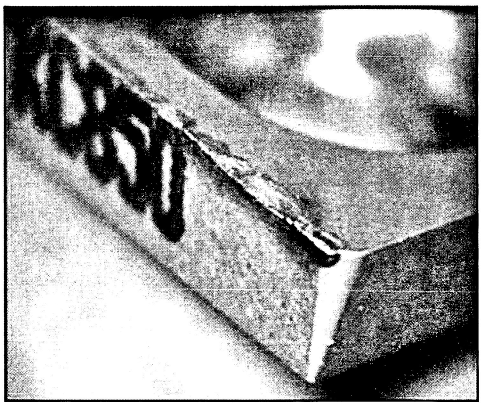

**Figure 6.** *Wear generated after machining Vanadis 10 with KC850 at feed rate 0.05 mm/rev, cutting speed 80m/min, and axial depth 0.1mm*

The flank wear, plastic deformation, and crater wear for cutting tool as shown in Figures 6 and 7 are similar to the cutting tool in Figures 4 and 5.

In terms of surface roughness, values recorded for all the cutting conditions especially at a speed of 80 m/min for KC850 and K313 tools shows there is a large variation between these tools as shown in Figure 8. The large variation is because the type of cutting tools and cutting depth played a significant role to generate this variation.

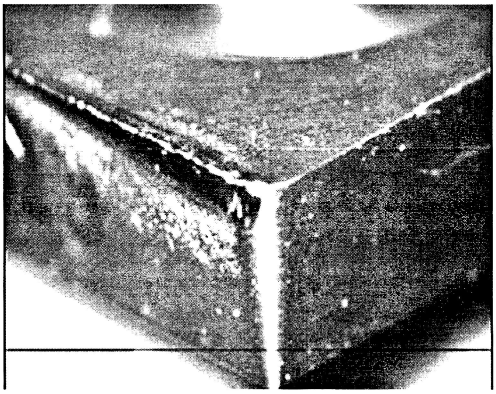

**Figure 7.** *Wear generated after machining Vanadis 10 with K313 tool at cutting speed 80m/ min, feed rate 0.05mm/rev, and axial depth 0.1mm*

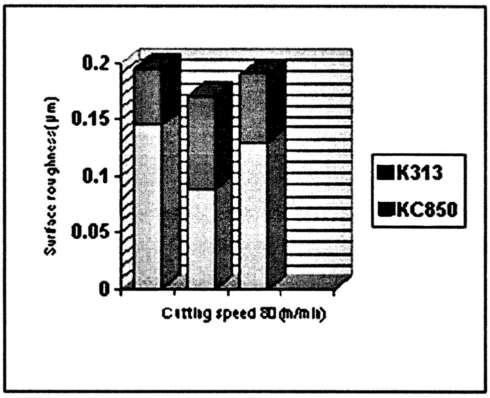


**Figure 8.** *Surface recorded when machining at cutting speed 80m/min.*

## CONCLUSIONS

The K313 tool gives better performance in terms of tool life and surface roughness compared to KC850 tool. The higher wear rate appeared when machining Vanadis 10 with KC850. The life of K313 and KC850 tools is significantly increased at lower cutting speeds. Increase in cutting speed generally led to increase in wear rate. Surface roughness increased when machining Vanadis 10 using K313 compared to KC850.

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## REFERENCES

American National Carbide Milling, Drilling and Boring Inserts Catalog and Technical Information, USA. (2005).

Beitzand, W. K., Kuttner H (1994) HB. mechanical engineering. Springer-verllag London limited.

Kennametal cutting tools- Catalog. (2004).

Khuri, *et. al,* (1996). Response surfaces, University of Florida, Markel Dekker, Inc, New York. (1996).

Monlgomery, D. C. (1997). Design and Analysis of Experiments, John Wiley and Sons, Inc. USA.

Sandvic Coromant, Die and Mould introduction, Sweden (2000).

Schey, J. A. (2002). Introduction to manufacturing processes, MC Graw-Hill, USA.

Serope K. (1995) Manufacturing engineering and technology, Wesley publishing company, Inc. USA.