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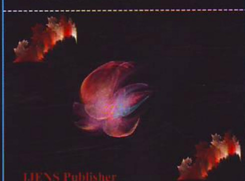

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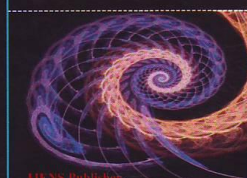

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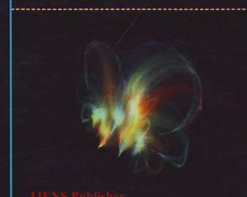

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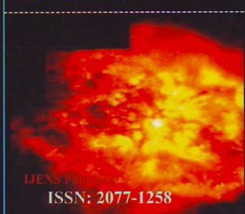

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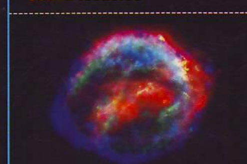

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Machine Vibration Analysis for Determining Optimum Operational Engine Speed

Gatot Pramuhadi, **Mad Yamin**, and **Siti Khoirunnisa**

Department of Biosystem and Mechanical Engineering,
Faculty of Agricultural Engineering and Technology,
Institut Pertanian Bogor, IPB Darmaga Campus PO Box 220 Bogor 16002
E-mail: gpramuhadi@yahoo.com

Abstract

The objective of the research was to analyse the amount of machine vibration and to approximate an optimum operational engine speed. The research was conducted on March 2009 until July 2009 in a dry field laboratory, Department of Biosystem and Mechanical Engineering, IPB, Bogor, West Java, Indonesia. Four operational engine speeds were applied to the five horsepower gasoline engine walking type cultivator and the amount of vibration on operator's hand was measured. When cultivator is operated on engine speeds of 1000 rpm, 1250 rpm, 1500 rpm, and 2000 rpm showed in variation of vibration on operator's hand. The vibration increases from 1000 rpm to 1250 rpm and then it decreases when the engine speed is increased after 1250 rpm up to 2000 rpm. The curve of the engine speed and the vibration relationship shows a polynomial equation. The equation is $Y = - 8.464 + 0.03196 X - 0.000012 X^2$, where Y is vibration ($m/s^2$) and X is engine speed (rpm). Based on the equation, it can be calculated that the highest vibration (12.816 m/s^2) is on 1330 rpm. Engine power is multiplication of torque and engine speed. Generally, a machine is operated on maximum torque for the best performance. When it is on that maximum torque, the machine vibration will be in maximum too. Based on the equation and the calculation, it can be approximated that optimum operational engine speed for soil cultivating is 1330 rpm. On that engine speed range, theoretically engine torque is in maximum range too. So, it can be recommended that the machine (i.e. the walking type cultivator) must be operated on engine speed range of 1330 rpm.

Background

In Indonesia, farm machinery always needed to increase effectiveness and efficiency on all farm fields. It can be achieved by applying high quality machines that had high pleasantness and safety.

An engine operated a machine. Generally, the engine was arranged on optimum crankshaft speed to obtain maximum torque in order to get maximum machine performance. During the operation, it appears vibrations from the engine, machine components, and interaction between the machine and other medias. It will influence the machine performance and especially toward operator's pleasantness and safety.

Generally, an engine performance was measured by a dynamometer to find out an engine characteristic curve. The curve tells a relationship between engine speed and engine torque and power. The usage of the dynamometer required an accurate measurement, so it can be tried to research another simpler method.

Objective

The objective of the research was to analyze the amount of machine vibration and to approximate an optimum operational engine speed.

Methods

The research was conducted on March 2009 until July 2009 in a dry field laboratory, Department of Biosystem and Mechanical Engineering, Institut Pertanian Bogor (IPB), Bogor, West Java, Indonesia.

Main research variables, which are used to analyze the amount of machine vibration and to approximate an optimum operational engine speed, are:

1. Vibration on hand's, or arm's, of operator
2. Engine speed.

Machines, tools, and instruments for conducting research consisted of:

1. one unit of walking type cultivator (5 hp gasoline engine, 2000 rpm)
2. one unit of four-wheel tractor
3. a vibration meter
4. a digital tachometer
5. a furrower (ridger)
6. a disk plow
7. some soil sampler rings
8. an oven.

Research design was made to approximate an optimum operational engine speed, as seen in Figure 1. The four-wheel tractor was used for disk plowing and then soil dry bulk densities at 5 locations were calculated to determine soil homogeneity. The walking type cultivator was used to cultivate soil after disk plowing. It can be seen in Figure 2. Maximum engine speed of the machine is 2000 rpm, so four engine speeds (i.e. 1000 rpm, 1250 rpm, 1500 rpm, and 2000 rpm) were arranged during the machine operations. Before soil cultivating, it is measured vibrations on stationary condition (Figure 3). On each soil cultivating (furrowing, or ridging), the values of vibration on the engine cylinder block and on operator's hand were measured. The measurement is on 3-axis (i.e. X-axis, Y-axis, and Z-axis). Vibration on the engine cylinder block and on operator's hand is resultant of vibration on the each three-axis. A curve of the machine engine speed and the vibration relationship was used to analyze and to approximate an optimum operational engine speed. The instruments that be used in the research can be seen in Figure 4, whereas the vibration sensors placement can be seen in Figure 5. Figure 6 showed the machine vibrations measurement in the field.

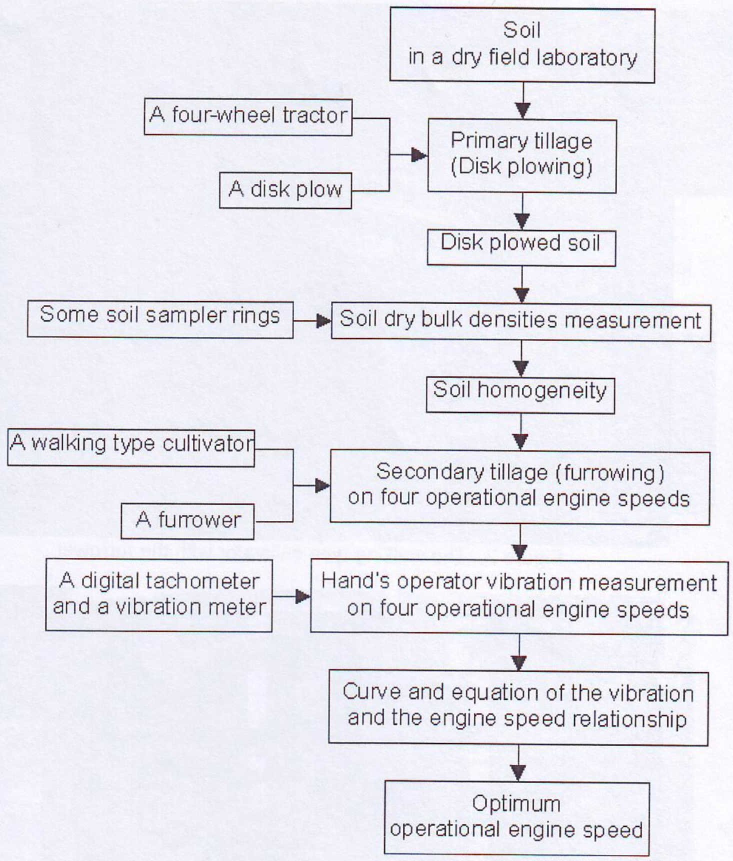
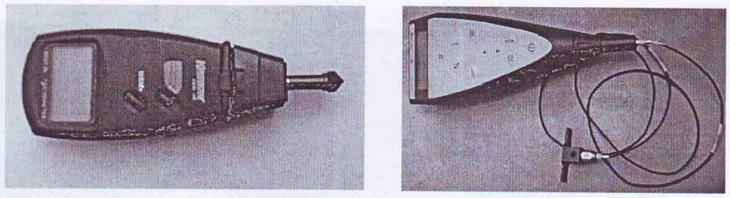


Figure 1. A schematic diagram of research design to approximate an optimum engine speed

Vibration was repetitive, periodic, and translation reactions of a mechanical movement system (de Silva, 1999). Sanders and Cormick (1987) illustrated two kind of vibration: (a) sinusoidal vibration, as a movement of one particle on an axis with certain frequency and amplitude, and (b) randomized vibration, as a non-regular vibration and unpredictable. Figure 7 showed the illustration of a sinusoidal vibration.

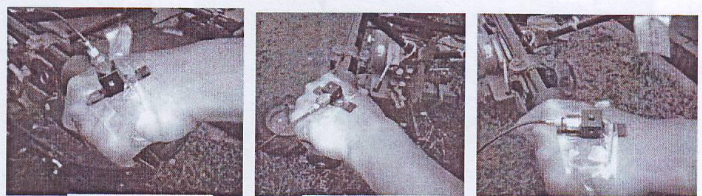
Figure 2. The walking type cultivator with the furrower

Figure 3. The machine vibrations measurement on stationary condition



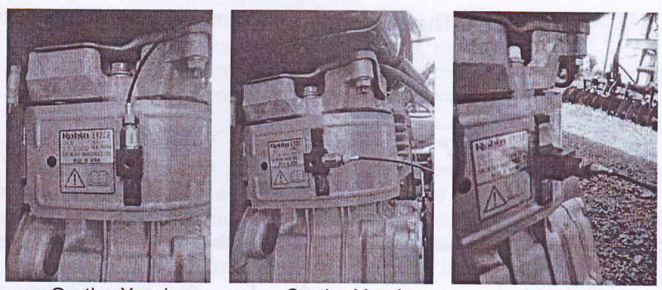
(a) (b)

Figure 4. The instruments that be used in the research: (a) the digital tachometer, and (b) the vibration meter



On the X-axis On the Y-axis On the Z-axis

(a)



On the X-axis On the Y-axis On the Z-axis

(b)

Figure 5. The placement of the vibration sensors on operator's hand (a) and on the engine cylinder block (b)

Figure 6. The machine vibrations measurement in the field

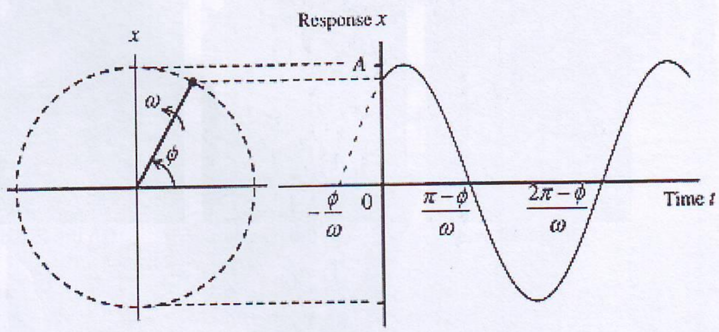


Figure 7. A sinusoidal vibration illustration (Sanders and Cormick, 1987)

Equations which be used to explain vibration in an acceleration unit were equation 1, equation 2, equation 3, and equation 4 below. Total vibration acceleration is shown in equation 5.

$$y = A\sin(\omega t + \theta) \quad (1)$$

$$v = A\omega\cos(\omega t + \theta) \quad (2)$$

$$\partial = -A\omega^2 \sin(\omega t + \theta) \quad (3)$$

$$\partial = -\omega^2 y \quad (4)$$

$$\partial_{h\partial v} = \sqrt{\partial_x{}^2 + \partial_y{}^2 + \partial_z{}^2} \quad (5)$$

Where:
y = vibration intersection, m
A = amplitude, m
ω = angular velocity, rad/s
t = time, s
θ = initial angle, rad
v = velocity, m/s
a = vibration acceleration, m/s^2
a_{hav} = resultant of vibration acceleration, m/s^2
a_X = vibration acceleration on X - axis, m/s^2
a_Y = vibration acceleration on Y - axis, m/s^2
a_Z = vibration acceleration on Z - axis, m/s^2

Results

The soil after disk plowing has homogeneous soil dry bulk density, that is between 1.0 g/cc and 1.2 g/cc in average at on 0 cm up to 30 cm depth, so that the soil condition before soil cultivating is uniform. It means that effect of the soil condition toward the machine performance is uniform too, so that the research results were influenced by the arrangement of the four engine speeds.

Table 1. Vibration acceleration on the engine cylinder block and on the operator's hand

Engine speed, rpm	Vibration acceleration, m/s^2							
	On the engine cylinder block				On the operator's hand			
	a_X	a_Y	a_Z	a_{hav}	a_X	a_Y	a_Z	a_{hav}
1000	1.49	1.10	2.28	2.94	8.07	6.23	5.44	11.55

1250	2.23	1.59	2.73	3.86	8.75	5.85	7.07	12.68
1500	4.10	1.92	3.95	6.00	8.22	5.38	7.88	12.59
2000	-	-	-	-	4.27	4.21	4.56	7.53

The calculation of vibration acceleration on the engine cylinder block and on the operator's hand is shown at Table 1 above. Vibration measurement on the engine cylinder block was conducted stationary, whereas vibration measurement on the operator's hand was conducted in the field during the machine operation. Engine vibration measurement was just up to 1500 rpm, because there was any trouble when it applied up to maximum engine speed (2000 rpm) that is the sensor cannot stick or adhere to the engine cylinder block.

Table 1 showed that vibration on the operator's hand is higher than on the engine cylinder block. It can be understood that the operator's hand vibration is a resultant vibration that it is influenced by vibration from the source of vibration i.e. engine and the tool (furrower) vibrations transmitted to the machine handlebar and the operator's hand, so that it will result in vibration amplitude.

The machine is the five horsepower gasoline engine, which has 2000-rpm maximum engine speed. When it is operated on engine speeds of 1000 rpm, 1250 rpm, 1500 rpm, and 2000 rpm showed in variation of vibration on the operator's hand. It can be seen in Figure 8.

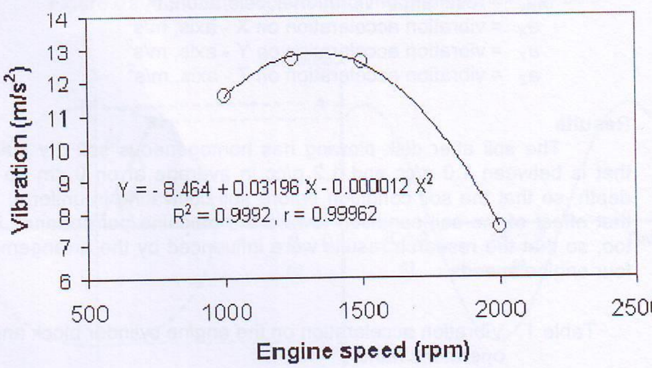


Figure 8. Relationship between operator's hand vibration and engine speed

The vibration increases from 1000 rpm to 1250 rpm and then it decreases when the engine speed is increased after 1250 rpm up to 2000 rpm. The curve of the engine speed and the vibration relationship shows a polynomial equation. The equation is Y = - 8.464 + 0.03196 X - 0.000012 X^2, where Y is vibration (m/s^2) and X is engine speed (rpm). Based on the equation, it can be calculated that the highest vibration (12.816 m/s^2) is on 1330 rpm.

The curve, as seen in Figure 8, can be connected to the curve of relationship between engine speed and engine torque of a tractor (Figure 9). It seem that the both curves have the same characteristic. So, we can state that there is any relationship between vibration and engine torque.

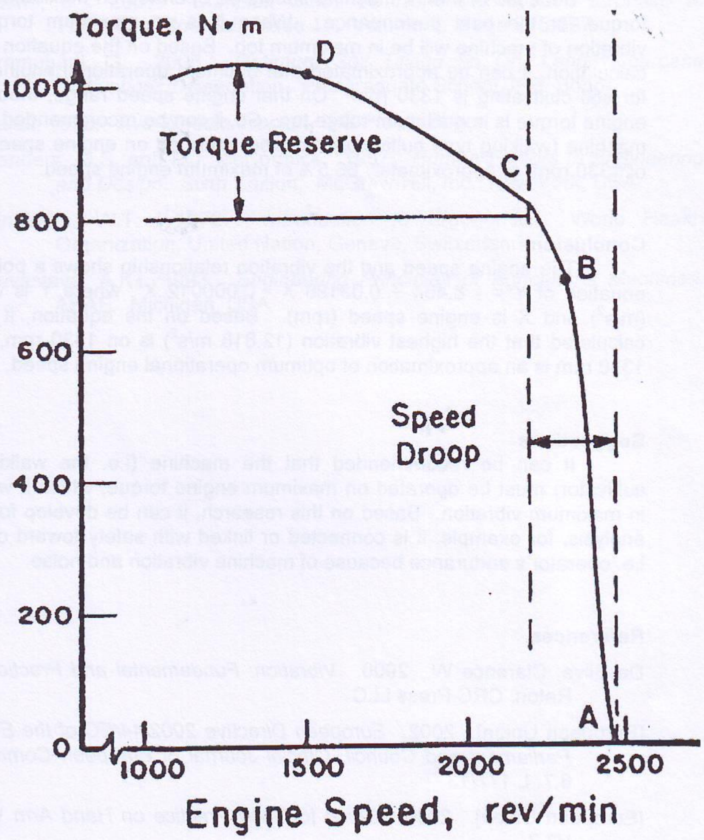


Figure 9. Relationship between engine speed and engine torque of a tractor (Srivastava, 1993)

Engine power is multiplication of torque and engine speed. Understanding the relationship between torque, power, and engine speed is vital in automotive engineering, concerned as it is with transmitting power from the engine through the drive train to the wheels. The gearing of the drive train must be chosen appropriately to make the most of the motor's torque characteristics. Power at the drive wheels is equal to engine power less mechanical losses regardless of any gearing between the engine and drive wheels.

Because of that, a machine should be operated on maximum engine torque for the best performance. When it is on maximum torque, the vibration of machine will be in maximum too. Based on the equation and the calculation, it can be approximated that optimum operational engine speed for soil cultivating is 1330 rpm. On that engine speed range, theoretically engine torque is in maximum range too. So, it can be recommended that the machine (walking type cultivator) must be operated on engine speed range of 1330 rpm, or approximately 66.5% of maximum engine speed.

Conclusions

The engine speed and the vibration relationship shows a polynomial equation of $Y = - 8.464 + 0.03196 X - 0.000012 X^2$, where Y is vibration ($m/s^2$) and X is engine speed (rpm). Based on the equation, it can be calculated that the highest vibration (12.816 m/s^2) is on 1330 rpm, so that 1330 rpm is an approximation of optimum operational engine speed.

Suggestions

It can be recommended that the machine (i.e. the walking type cultivator) must be operated on maximum engine torque, which it will result in maximum vibration. Based on this research, it can be develop for further analysis, for example: it is connected or linked with safety toward operator, i.e. operator's endurance because of machine vibration and noise.

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