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Optimization Design of Shovel Depth when Loader Shovelling Original Raw Soil

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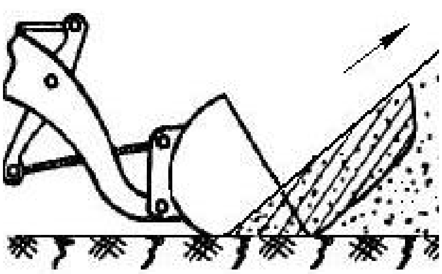
Abstract

The shovel depth generally references to the depth of material pile operation, or according to operators experiences to determine the depth while loader shovelling original raw soil. In view of this situation, the relationship between the shovel depth of loader bucket and shovel resistance is analyzed in this paper, and a mathematical model is constructed for calculating the time of the material filling up the bucket. Taking ZL50 loader as an example, and combined with the relationship curve of the bucket work resistance and the shovel depth, and the traction characteristic curve of I gear, the relationship of the driving speed and shovel depth is worked out, on the basis of this, the mathematical model of optimization algorithm of the shovel depth is established. The result shows that there is an optimal shovel depth when loader shovelling original raw soil, while the operation efficiency of loader is the highest, and there is a best operation depth range of loader shovel, in which work efficiency of loader changes a little, this will bring great convenience to the operation for the driver.

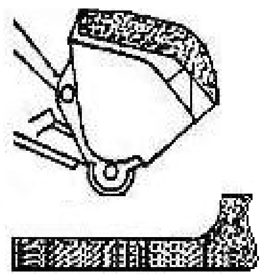
Keywords: *loader, original raw soil, shovel depth, optimization design*

1. Introduction

The wheel loader is a shovel and transportation machinery which is widely used in engineering and urban construction sites such as roads, railways, ports, docks, mining, water conservancy and national defense. It is commonly used in handling material, as shown in Figure 1(a), and it can also be used to strip original raw soil, as shown in Figure 1(b).



(a) insertion material pile for shovelling



(b) stripping original raw soil

Figure 1. Operation Method of Loader Shovelling Soil

When the overall performance parameters of loader match reasonably, it is very important to choose a reasonable shovel depth of loader bucket for improving production efficiency [1-3], as shown in Figure 1(a), it is one of the basic practices for loader, some literatures [4-7] have discussed the shovel depth of the bucket in such practices. The operation type used frequently for loader shovelling original raw soil is shown in Figure 1(b). The shovel depth generally references to the depth of material pile operation, or according to operators'

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experiences to determine it while loader is shovelling original raw soil [8]. In this paper, ZL50 loader is taken as an example to research the optimization method of the shovel depth.

2. Operation Course of Loader Shovelling Original Raw Soil

The productivity of loader can be calculated by Equation (1):

$$Q = \frac{3600q}{t + t_0} \tag{1}$$

Where Q is the productivity of loader, the number of cubic meters of loading and unloading material per hour (/m^3·h^{-1}), q is the earthwork quantity of each operation cycle (/m^3), t is the required time for shovelling of each operation cycle (/s), and t_0 is the required time for driving and unloading soil of each operation cycle (/s).

The completed earthwork quantity q in each operation cycle depends on the bucket capacity, in the situation of certain bucket capacity, shortening the t and t_0 can improve the productivity. This paper mainly discusses how to select the appropriate shovel depth to shorten the time t of shovelling soil.

As shown in Figure 2, when loader shovelling original raw soil, the bucket firstly inserts into the soil at point E, we assume the shovel depth is x, and after moving a total distance of $l_0 + l_1$, loader bucket has been filled with the material, thereinto, l_0 is the length of the bucket bottom. The material fills the bucket in two stages, in OA segment, the loader drives forward while the bucket inserts into the material and the shovel depth gradually increases; In AB segment, the shovel depth no longer changes, and to point B, the bucket is full of the material.

The material swarming into the bucket in OA segment can be calculated by Equation (2):

$$V_1 = BS_1 \tag{2}$$

Where V_1 is the volume of the material swarming into the bucket in OA segment (/m^3), B is the width of bucket inside wall (/m), and S_1 is the area of triangle ADE (/m^2).

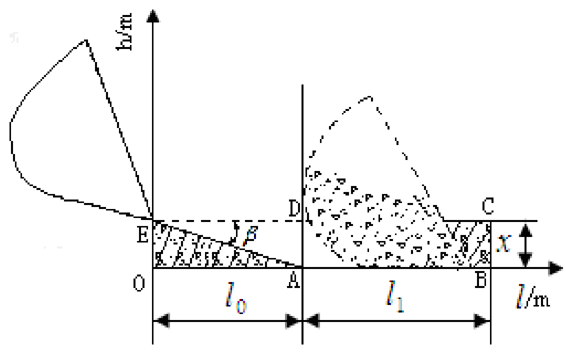

Figure 2. Loader Shovelling Original Raw Soil

The material swarming into the bucket in AB segment can be calculated by equation (3):

$$V_2 = BS_2 \tag{3}$$

Where V_2 is the volume of the material swarming into the bucket in AB segment (/m^3), and S_2 is the area of rectangle ABCD (/m^2).

During a work cycle of loader, when the bucket is full of the material, it shall be:

$$V = V_1 + V_2 \tag{4}$$

Where V is the capacity of the bucket (/m^2).
Thus,

$$S = S_1 + S_2 = 0.5xl_0 + xl_1 \tag{5}$$

Where S is the side area of the bucket (/m^2).

We can know from Equation (5) when the loader bucket is full of the material, the horizontal distance the bucket needs to move is:

$$l = l_0 + l_1 \tag{6}$$

In OA segment, the shovel depth grows gradually, and the resistance of the bucket increases sharply with the increase of the shovel depth, the bucket resistance can be calculated as follow [4, 5]:

$$F = 100B \times K \times e^{3.4208x} \tag{7}$$

Where F is the horizontal resistance of the bucket (/N), K is the parameter related to the type and state of shovelling material, and x is the shovel depth of the bucket (/m).

3. Mathematical Model of Calculating the Shovelling Time

In OA segment, the driving speed of loader decreases with the increase of the shovel resistance, the time for moving distance l_0 can be calculated as follow [4]:

$$t_1 = tg^2\beta \int_0^x \frac{1}{v} dx \tag{8}$$

Where x is the shovel depth when the bucket being full of material (/m), v is the driving speed of loader (/m·s^{-1}), and β is the insertion angle of the bucket (/º), as shown in Figure 2, $tg\beta = \frac{x}{l_0}$.

In AB segment, it can be considered that the resistance of the bucket at point A remains unchanged, and loader keeps moving uniformly at present speed v_x. Thus the time for moving distance l_1 is:

$$t_2 = \frac{l_1}{v_x} \tag{9}$$

Therefore, under these conditions, the required time for moving distance $l_0 + l_1$ is:

$$t = t_1 + t_2 = tg^2\beta \int_0^x \frac{1}{v} dx + \frac{l_1}{v_x} \tag{10}$$

4. Construction of the Objective Function

In this paper, we take ZL50 loader as an example and give the optimization method of the shovel depth of the bucket. The relevant parameters [4-10] are as follows: bucket width B =2.87m, the material is original raw soil, inside friction angle of the material φ =30º. Meanwhile, the parameter associating with the type and state of the material K =8.2712 [4], according to Equation (7), we can obtain the shovelling resistance of the bucket as shown in Figure 3.

When loader shovelling the soil, it is driven by I gear, the driving speed depends on the shovelling resistance and the traction characteristic curve of gear. The traction characteristic curve of I gear of ZL50 loader [11] is shown in Figure 4.

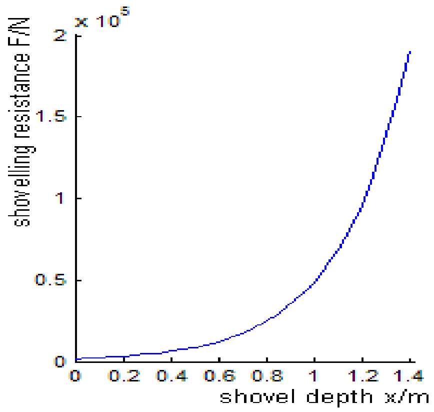

Figure 3. Shovelling Resistance of the Bucket

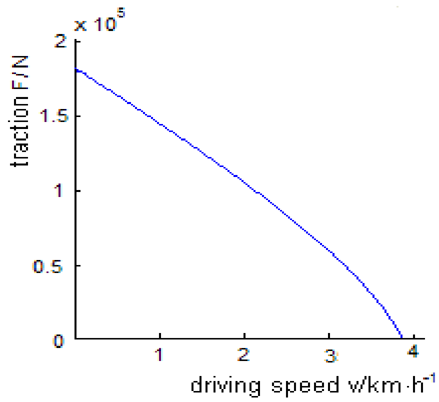

Figure 4. Traction Characteristic Curve of I Gear of ZL50 Loader

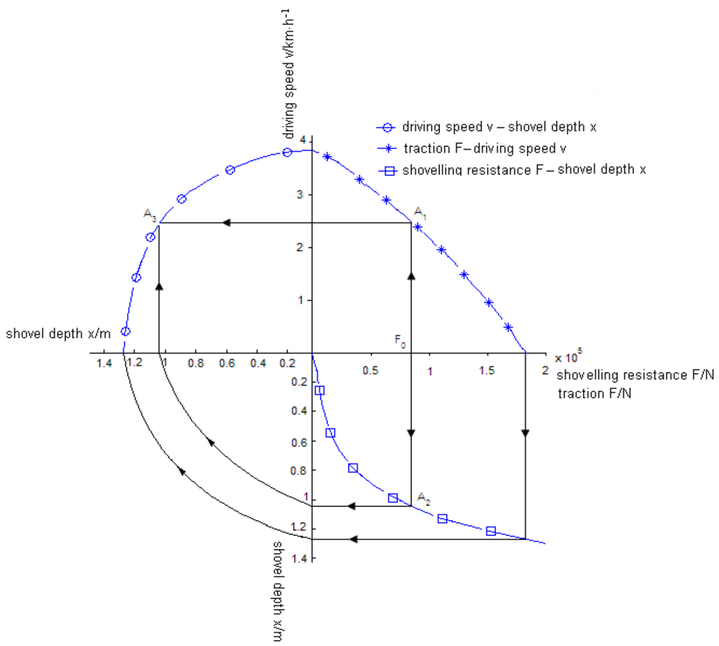

Figure 5. The Relationship between the Driving Speed and the shovel depth of loader

Combined with the relationship curve of the working resistance and the shovel depth of bucket, and the traction characteristic curve of I gear of ZL50 loader, the relationship between the driving speed of loader and the shovel depth of bucket can be worked out. When drawing the working resistance curve of the bucket and the traction characteristic curve of I gear on the same graph (namely Figure 5), and taking equal force in the working resistance curve of bucket and the traction characteristic curve of I gear (point A_1,A_2 in Figure 5), the corresponding force is F_0, and according to the method shown in Figure 5, the intersection point A_3 will be found. With the same way, we can find more points, and obtain the relationship curve between the driving speed of loader and the shovel depth of bucket, the Equation [4] is:

$$v = \frac{v_0}{x_{\max}}\sqrt{(x_{\max}^2 - x^2)} \quad (11)$$

Where v_0 is the theoretical speed of low gear (/km·h^{-1}), and $x_{\max}$ is the maximal shovel depth when the bucket being full of material (/m).

From Figure 4, we can know that in this example v_0 =3.84km/h, namely v_0 =1.07m/s and from Figure 5, we can obtain $x_{\max}$ =1.27m, therefore, the relational equation about the driving speed of loader and the shovel depth of bucket is:

$$v = \frac{1.07}{1.27}\sqrt{1.27^2 - x^2} \quad (12)$$

Moreover, in this example, the side area of bucket S =0.9m^2, the length of bucket bottom l_0 =0.96m. From Equation (5), we can know:

$$l_1 = \frac{0.9 - 0.48x}{x} \quad (13)$$

After putting Equation (12) and (13) into Equation (10), we can obtain:

$$t = \frac{x^2}{0.92}\int_0^x \frac{1.27}{1.07\sqrt{1.27^2 - x^2}}dx + \frac{1.27\times(0.9 - 0.48x)}{1.07x\sqrt{1.27^2 - x^2}} \quad (14)$$

Equation (14) can be further simplified as:

$$t = 1.29x^2 \arcsin\frac{x}{1.27}\bigg|_0^x + \frac{1.07 - 0.57x}{x\sqrt{1.27^2 - x^2}} \quad (15)$$

Namely:

$$t = 1.29x^2 \arcsin\frac{x}{1.27} + \frac{1.07 - 0.57x}{x\sqrt{1.27^2 - x^2}} \quad (16)$$

Equation (16) is the objective function which shows the relationship between the required time of bucket being full of material and the shovel depth of bucket.

5. Optimization and Analysis

The relationship curve between the time of bucket being full of material and the shovel depth of bucket is given in Figure 6.

We can see from Figure 6 that there is an optimum shovel depth x0, at this point the operation efficiency of loader is the highest, the corresponding working condition is the economical operation condition for loader. In fact, the corresponding resistance value of this shovel depth is the economical traction value when loader shovelling original raw soil.

We can also find from Figure 6 that in a larger range of the optimum shovel depth x0, the corresponding t value of the shovel depth x increases a little, it indicates that the optimum shovel depth of loader bucket is not limited to one point, but a range, generally the range is 1 to 1.1 times of the corresponding operation efficiency of the optimum shovel depth[12][13], the corresponding shovel depths are respectively x1,x2. In Figure 6, x0=0.36m, x1=0.23m, x2=0.47m. Therefore, when the shovel depth of bucket is in the range 0.23m to 0.47m, all the operation conditions belong to the economic operation conditions. This will bring great convenience to the drivers operations.

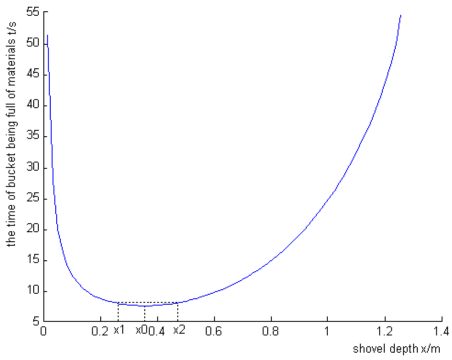

Figure 6. The Relationship Curve between the Time of Bucket being Full of Material and the Shovel Depth

6. Conclusion

In summary, when ZL50 loader shovelling original raw soil, the optimum shovel depth is 0.36m; the shovel depth range under the best economical operation condition is from 0.23m to 0.47m.

According to the results of optimization and calculation of this example, the following conclusions can be drawn:

(1) When loader shovelling original raw soil, it is not beneficial to improve operation efficiency if the shovel depth is too large or too small. There is an optimum shovel depth, and the operation efficiency of loader is maximum at this time.

(2) There is a best range of the bucket shovelling depth, during this range, the operation efficiency of loader changes a little, it will bring great convenience to drivers' actual operations.

Acknowledgments

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