Simulation curves of scooping and digging grab

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Abstract. The article deals with a brief description of the purpose and scope of the exchangeable working equipment on cranes and excavators. It is shown that two-leaf rope grab during the cycle can scoop loose material or excavate the ground with digging. In the latter case, the edge of the leaf is equipped with teeth and the specific mass of the bucket per cubic meter of its capacity should be much heavier than with scooping.. An apparent discrepancy between the curve needed for obtaining the greatest grabbing of loose material or ground, i.e., a geometric curve that does not take into account the operational factors of the process, and its actual curve is revealed. In the case of working on the ground, it is called the trajectory of digging. The introduction of the concept of "simulation curve" is an innovative moment in the work. It means the trajectory that adequately adapts the actual geometry of the scooping trajectory or the digging one. The method of geometric construction of the scooping trajectory and the digging one without operational factors is provided.. The method of constructing adequate simulation curves and calculating the volume of portions of material when scooping or digging is outlined.

1 Introduction

Integrated mechanization and automation of excavation and loading and unloading works in the period of prolonged import substitution with appropriate equipment are one of the urgent issues. The using of exchangeable grab working equipment might be a partial solution of work minimization with small production volumes especially in space-limited environment. According to the operational purposes, grabs are divided into excavation, reloading and technological [2, 8]. A characteristic feature of the first grab, excavating the ground with digging, is a large own mass and, as a rule, the presence of teeth on the cutting edges of the leaves [3, 4]. A design feature of the bucket comprising a pair of closing leaves, allows working "in depth" without expanding the boundaries of the digging area [5, 7, 10]. According to the motion trajectory of the leaves during cargo grabbing, digging and scooping trajectories are distinguished. During the work the cutting edges of the leaves of the digging grabs are deepened into the ground, dig it by separating the chip from the array. In scooping grabs, the leading edges of the jaws move along the "scoop curve».

Grab mechanisms have a large nomenclature of standard sizes and designs. So, in the economy the most common is two-rope grab composed of two leaves, which are pivotally connected to the lower beam and with the help of rods with a head. The grab operates as follows. When the closing rope is loosened, the grab is held by a supporting rope attached

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to the upper head of the grab. Under the effect of its own weight, the lower beam is lowered together with the lower blocks of the block and tackle of the closing rope mounted on it and is pivotally fixed leaves.

2 Materials and Methods

The grab as a certain invariable system can make three translational and three rotational motions in the space. In suspension the rope grab can have five motions on crane boom or an excavator on a flexible thread or ball bearing. The sixth motion - descent - is carried out with a vertical ascent or descent, which partly determines the shape of the curve of scooping or digging. In case of the fixed beam, the system turns into a crank mechanism, the position of the links of which is determined by the angle of rotation of the leaf. The construction of theoretical curves of scooping or digging makes it possible to obtain the points position on the arch of the recess at any time of leaf closure. So far, there is no a derivation of the general equation of the trajectory of the leaves cutting edge, taking into account the operational, constructive, kinematic and other factors that arise during the work process [6, 8]. One of the ways of the local particular solution of the task can be considered the graphical determination of points location with the help of serifs, creating the kinematic position of the edges of the bucket leaves on the flat fractional section of the bucket from the first moment of the process to their complete closing. As a pilot object of research, a laboratory model of the grab bucket located in a ground channel was selected [9, 13].Without claiming to a complete kinematic analysis of the grab mechanism in the process of leaves closure, arc curves of "scooping" and "digging" were built on the basis of the actual linear and angular parameters of the grab bucket model. As key constants, the actual linear dimensions of the links of the grab laboratory model are used, such as: - radius of the bucket cutting edge R_E = 260 mm; - the radius of the anchor rod point to the trailing edge of the bucket bottom R_T = 250 mm; - length of traction L_T = 310 mm; the expansion angle of the bottom line in the plane of the leaf is 68^0. The values of the remaining desired and variable values when graphically construction the scooping and digging curves are shown in the figures (Figure 1, Figure 2, Figure 3).

Studies of the scooping and digging process on the grab bucket model showed that the cutting edges of the cheeks move not along a circular arc with a radius R_E, but along a parabolic curve with a probable changing radius R, because the movement resistance in the loose material or during excavation is changing values. Since the graphical construction of the curves of scooping and digging formally excludes the effect of operational factors, it was suggested to introduce the concept of "simulation curve" that adequately replaces the arc with radius R. By the way, the concept of "simulation chip configuration" and "simulation configuration of the material volume" is introduced for future further studies of the power parameters of the digging and scooping process.

The initial parameter for drawing a static scheme of the scooping curve can be the depth of the recess in the loose material at the moment of the leaves closure. When digging the same parameter is determined by the thickness of the ground chips, which is separated from the face at the moment of the leaves closure. The average statistical value of this quantity for the laboratory grab is C_{max}= 0.135 m.

3 Results

3.1 Construction of the scooping curve

The construction of the scooping curve is given in Figure 1 and is carried outin two stages. In the first stage, the construction of the trajectory of the leave leading edge is implemented, and in the second one is the construction of the trajectory of the anchor rod point to the trailing edge of the leaf, the kinematics of which determines the shape of the scooping curve. In the first stage, the trajectory of the point of the leading edge of the leaf is constructed, for which:

1.The rotation angle of (90^0) the point of the leading edge of the leaf A_0 with a radius R_E= 0.26 m until the leaves closure (point K) is divided into four equal angular parts of 22.5^0 each. From the point C_0 of the central hinge of the beam, we trace degree rays towards each of the fourth part of the arc of the leaf edge in degrees.

2. The travel of the central hinge of the beam along the vertical during the period of moving the point A_0 to the point of leaves closure (point K) is equal to the difference (R_E– C_{max}), which in the numbers is: 0.26 m – 0.135 m = 0.125 m, and we also divide by four equal parts (0.125 m: 4 = 0.031 m). As a result of this division, we obtain the points C_0, C_1, C_2, C_3, C_4.

3. From each point (C_0, C_1, C_2, C_3, C_4) with radius R_K we successively make a marks on the relevant degree ray and obtain the discrete points A_0, A_1, A_2, A_3, A_4, the closing line of which forms the scooping curve.

The second stage reproduces the trajectory of the attachment point of one end of the traction to the trailing edge of the line of the leaf bottom (point B_0). This point drives traction 3, acting as a connecting rod, rotating the crank with a radius R_T = 0.25 m. For the cycle of rotating the leading edge by 90^0, the point B_0 rotates by 68^0 and its motion trajectory is constructed as follows:

1. The total angle of rotation of the point B_0 per cycle divide by four equal parts (68^0: 4 = 17^0) by 17^0 each, and in these directions from the point B_0 we trace the degree rays (0^0; 17^0; 34^0; 51^0; 68^0).

2. From each point (C_0, C_1, C_2, C_3, C_4) with radius R_T we successively make a markon the relevant degree ray and obtain the discrete points B_0, B_1, B_2, B_3, B_4, the closing line of which forms the curve line of the connection point movement of the connecting rod (of one end of the traction) with a crank providing the scooping curve.

3. The other end of the traction is attached to the head of the grab. Their connection point is on the vertical, drawn through the hinge of the anchor rod to the head, as a factor of the sixth vertical motion. To obtain the coordinates of these points when rotating the trailing edge of the leaf by 68^0, and the leading edge at the same time by 90^0, we make a radius equal to the length of the traction L_T = 0.31 m from the points B_0, B_1, B_2, B_3, B_4 of the mark on the vertical, passing through the hinge of the anchor rod to the head and obtaining the points D_0, D_1, D_2, D_3, D_4. The distance between these points is not the same, which indicates the complexity of the kinematics grab bucket, although the identity of the points trajectories of A and B is obvious.

3.2 Construction of the digging curve

The digging trajectory of various types of digging machines depends on their purpose and, of course, the respective design solution [4].

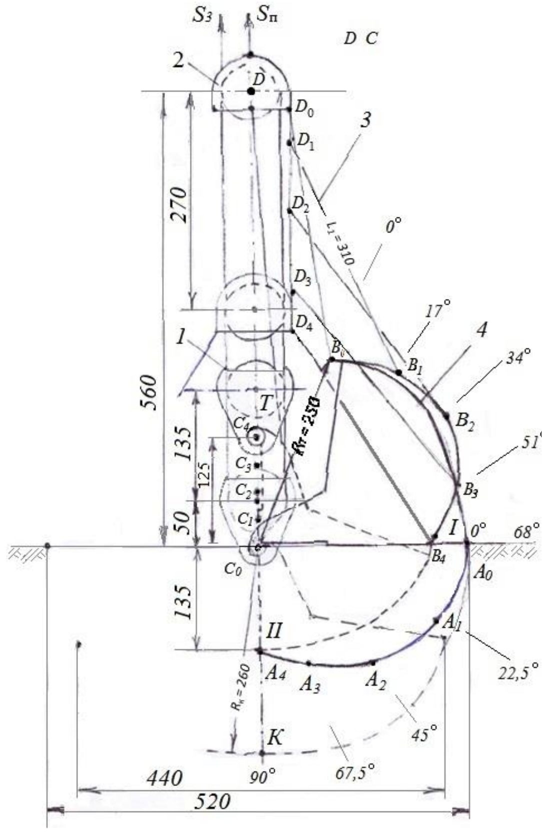

Fig. 1. Scooping curve.

1- Beam; 2- Head; 3- traction (connecting rod); 4- Leaf of the bucket (bottom line of the Leaf)

So for excavators, the most common trajectory of the leading edge of the bucket is the arc of the trochoid, circle or line on the surface of the torus. Curvilinear trajectory in the form of an arc of a circle should have also cutting edges of a grab bucket, as most desirable on kinematic and operational indicators. If we put a grab bucket with a full swing of leaves the size of 0.52 m (Figure 2) on the horizontal daylight surface of the ground, then their cutting edges will occupy the positions of points H to the right of the central hinge of the beam and H to the left of it. The formal trajectory of one leaf digging along the H-K_0 line with a restrained beam will be described by one-fourth of the arc of a circle of radius R_E = 0.26 m., drawn from the central hinge of the beam (point C_0) lying on the daylight surface of the ground [11, 12]. The ground volume of this sector largely exceeds the half the capacity of the laboratory grab bucket. Therefore, the construction of the simulation digging curve is to the construction of the motion of the point - C the connection of the bucket bottom with radius R_T = 0.25 m, with one end of the traction L_T = 0.31 m. In this case, we set the simulation digging curve in the form of a circle with radius R_E = 0, 26 m., and the center at the point C_0 (the central hinge of the beam), raised above the level of the daylight surface of the ground by 0.125 m., ensuring the maximum simulation thickness of the chip C_{max} = 0.135 m and the swing of leaves is 0.46 m. Further construction includes the following:

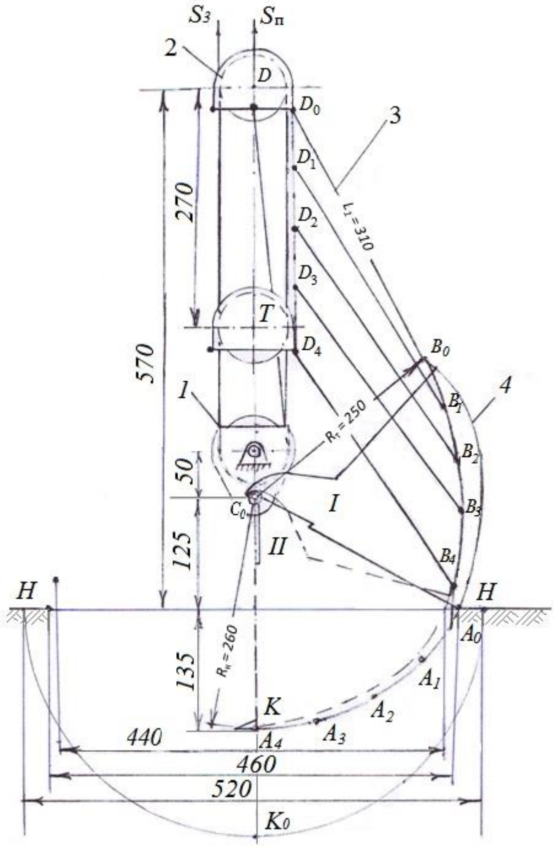

Fig. 2. Digging curve.

1- Beam; 2- Head; 3- traction (connecting rod); 4- Leaf of the bucket (bottom line of the Leaf)

1. From the point C_0 (the center of the hinge of the restrained beam) by the digging radius R_E, we make a mark on the line of the daylight ground surface and obtain the point A_0 - the beginning of the face digging process.

2. We draw the required digging trajectory in the form of an arc of a circle from the point A_0 to the intersection with the vertical passing through the center of the hinge of the beam and obtain the point -K corresponding to the moment of the leaves closing.

3. We divide the angle of the complete digging arc (60^0) into four equal parts by 15^0. From point C_0 we trace the degree rays with a step of 15^0. The intersection of these rays with the given digging arc forms the pointsA_0, A_1, A_2, A_3, A_4, connecting them by a solid line we obtain the simulation digging curve. The interesting side of this tracing is that the curve of the leaf bottom of the laboratory bucket (the dotted curve from point B_4 to point K) normally fits into the simulation digging curve with a gap, which eliminates the friction of the bottom along the face.

4. In order to actually obtain this curve, it is necessary to set the normative trajectory of the point C motion, in which the trailing edge line of the bottom of the bucket (R_T = 0.25 m.) and one end of the traction (L_T = 0.31 m) connect. The movement of the cutting edge of the leaf along the simulation scooping curve was due to the lowering of the axis of the blocks D of the grab head by 0.27 m. We divide this distance into four equal parts of 0.067 m each, and from the five points obtained, D_0, D_1, D_2, D_3, D_4, in which the second end of

the traction appears successively, we make marks equal to the length of the traction L_T = 0.31 m.

5. From points A_0, A_1, A_2, A_3, A_4 with a radius equal to the distance between the points A_0 and B_0, we successively make marks whose intersection with the corresponding marks from the points D_0, D_1, D_2, D_3, D_4 form the points B_0, B_1, B_2, B_3, B_4. By connecting these points with each other by a continuous line, we obtain an arc of the active trajectory of the tail part of the leaf, which provides the simulation digging curve in the form of an arc of a circle.

4 Discussion

Both the scooping trajectory and the digging trajectory depend on the ratio of the trajectories of the points C and B. The motion of the point B occurs along a straight vertical line. When scooping up (Figure 1) with a laboratory bucket, this point moves from position C_0 to position C_4 upwards by a distance of 0.260 m. - 0.135 m. = 0.125 m. When constructing the digging trajectory (Figure 2), the initial distance of the central hinge of the beam, indicated by the point C_0 is at the same distance from the daylight ground surface and is fixed (point T) in a position ensuring the operational parameters of the digging process. The movement of point B during digging is along a sloping curve than scooping, which explains the greater curvature of the scooping trajectory than the digging trajectory. This curvature causes an increase in the volume of loose material extracted from the embankment during the scoop cycle. But at the same time, the digging possibility of the ground is excluded along this trajectory.

4.1 Bucket capacity and volume created by simulation curves

The initial parameter for determining the capacity of the grab bucket can be considered the depth of the recess in the loose material when scooping or the chip thickness when the leaves are closed. The size of these values is further indicated by the size of C_{max}. According to these and the associated values of the additional parameters, the areas of the segments rounded by the simulation curves are calculated. These areas, multiplied by the inside width of the bucket b or the width of the recess b_1, determine the bucket capacity, the volume of the portion of the scooped material or the excavated ground (Figure 3) in one working cycle.

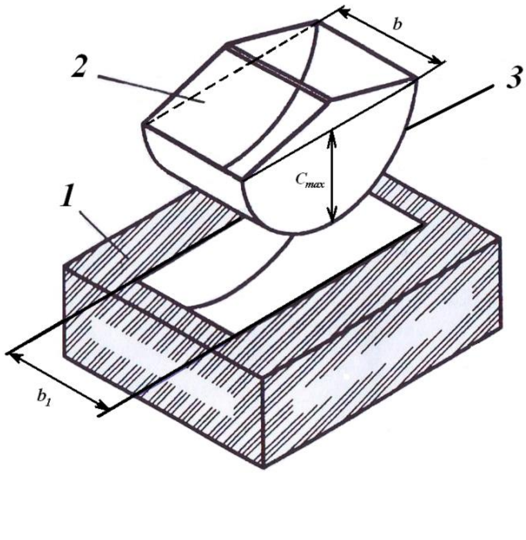

Fig. 3. Segment of the scooped material or excavated ground.
1. Recess; 2. The figure of the extracted material or ground; 3.Simulation curve.

These calculated studies consist of three parts [15]. The first «**A**» determines the actual capacity of the laboratory bucket; in the second «**B**» we find the volume of the excavated ground by the bucket per cycle; in the third «**C**» part, we set the volume of extracted material when scooping (Figure 4).
«**A**». The position of the bucket's cheeks is indicated by Roman numerals I-I (Figure 4).

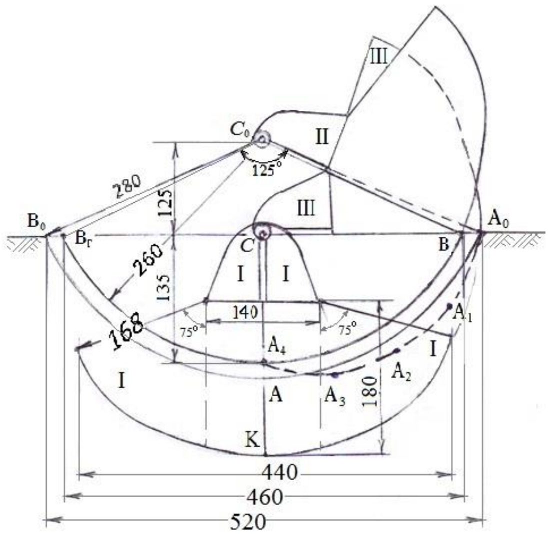

Fig. 4. The area of the bucket leaves of the, simulation digging and scooping segments.

I-I - closed leaves of the bucket; II-II –leaf at the beginning of digging; III-III - leaves at the beginning of the scoop process.

1. The area of closed cheeks can be defined as the sum of the areas of a rectangle with dimensions of 0.14 m. ×0.18 m. = 0.025 m^2.
2. The area of two sectors of circles with a radius of 0.168 m and with a total central angle of $75^0 + 75^0 = 150^0$ is 0.036 m^2.
3. The total area of the bucket's longitudinal section is 0.061 m^2.
4. The calculated capacity of the bucket with an internal edge width of 0.235 m is 0.014 m^3.
«**B**». The position of the cheek at the beginning of excavation is indicated in Roman numerals II-II (Figure 4).
1. Area S of the segment of the simulation circle with radius $R_E = 0.26$ m, the beginning of digging at point C, the central angle $\alpha = 125^0$ with the maximum chip thickness C_{max} = 0.135 m is determined by the formula:

$$S = 0{,}5 \bullet [C_{max} \bullet b + R \bullet (L - b)] \text{ , m}^2, \quad (1)$$

where: b = 0,46 m. is the chord of the B-B segment;
L = 0.566 m is the length of B_r-A_4-B arc line of the simulation circle.

The calculated area of the digging segment is 0.044 m^2, and its volume with a recess width of 0.25 m is 0.011 m^3. Even taking into account the loosening coefficient, this portion volume is placed in the grab bucket.
«**C**». 1. In Figure 4 the scooping trajectory for the cheek with the designation position III-III is described from the beginning of scooping (point A_0) of curve A_0, A_1, A_2, A_3, A_4. This curve can be adequately adapted by the simulation circle with a radius $R_3 = 0.28$ m.

2. The area of the segment limited by the arc A_0-A-B_0 and the chord A_0-B_0 calculated according to the above formula and is equal to 0,056, and its volume with the width of the recess equal to 0.25 m is 0.014 m^3. Since the loose material is scooped up, this portion volume can be placed in the bucket.

5 Conclusion

The use of proposed method of simulation curves simplifies the kinematic motion calculations of the grab bucket links. This, in turn, for the future involves the possibility of taking into account the operational characteristics of the scooping and digging process, and also allows determining the parameters of the grab bucket, including its mass for specific working cycle conditions. In this case, the results of experimental research on a laboratory bench with grab equipment using a combination of physical and mathematical modeling methods will be used [1, 14].

References

1. V.I. Balovnev, *Similarity and modeling in the system of designing road-building machines* (M .: MADI, 148, 2014)
2. A.A.Vainson, *Hoisting-and-transport machines* (M.: Mechanical Engineering, 430, 1975)
3. Grapples rope for bulk cargo. Typical strength calculations. Methodology. **RD 31.46.07-87** (M.: V/O "Mortejinform - advertising", 144, 1987)
4. N.G. Dombrovsky, *Excavator* (Moscow: Mashinostroenie, 317, 1969)
5. P.P. Ipatov, E.Yu. Pasechnik, *Machinery and equipment for environmental management and water use* (Tomsk: Publishing house of Tomsk Polytechnic University, 296, 2012)
6. B.V. Krasnovshek, *Technology and mechanization of construction processes* (UMK, FEFU, LLC Prospect, Electronic version, 2015)
7. N.S. Sevryugina, A.A. Bozhanov, News of Orel State Technical University. Series: Building and transport, **12**, 77-80 (2006)
8. B.A. Tauber, *Grapple mechanisms* (M. Mechanical Engineering, 272, 1985)
9. I.L. Tsipurskiy, *Settings digging and recruitment earthmoving machines* (M.: textbook/Publisher ASV, 223, 2016)
10. I.L.Tsipurskiy, M. Mechanization of construction, **4**, 20-23 (2010)
11. I.L.Tsipursky, J. Construction and road machines, **9**, 9-10 (1988)
12. I.L.Tsipurskiy, M. Construction and Road machines, **9**, 17-19 (2010)
13. I.L.Tsipurskiy, MGSU M., 56 (2011)
14. I.L.Tsipurskiy, M. J. Mechanization of construction, **12**, 54-57 (2017)
15. I.L.Tsipurskiy Production skills and the PC in training of students.// IC EMMFT-2017, DOI Org10.007, AISC.