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Calculation and Choice of Grip Parameters for Garbage Truck Manipulator

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Abstract

Around the world the issue related to municipal solid waste (MSW) management ranks second in urban economy system. For the most part the actual researches deal with the improvement of MSW recycling, neutralization, utilization and burying processes. The garbage trucks are initial unit in a processing chain of MSW utilization. As to the garbage trucks operation management issues the researches are carried out on the enhancement of designs, maintenance and repair system, models and methods of work route schedules development. The free oscillations of the vehicle frame are not taken into account in the fundamentals of garbage trucks engineering design.

As part of the fulfilled research the process modeling of side mechanized loading of solid waste in the garbage truck body, taking into account the vehicle frame free oscillations, is carried out. As result the constructive and connecting sizes of a new grip design to ensure minimum stresses and moments generation in «grip-container-grip» system are determined.

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Keywords: garbage truck; manipulator; grip; load; moment; modeling; parameters optimization

1. Introduction

The problem of municipal solid waste (MSW) management is a priority worldwide, ranking second in the urban economy taking into account costs and investments after the water and canalization sector [1]. In order to protect the

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natural environment, air and water resources the researches are carried out in the world and domestic practice in the field of ecology, economics, engineering and technology of MSW management [2-12]. The special mobile units, named garbage trucks are initial unit in the process chain of solid waste disposal. The garbage trucks with mechanized body side-loading are the most widely used [13]. The garbage trucks operating efficiency depends on the organization and improvement of the three main processes: collection and disposal of MSW, as well as maintenance and repair (M&R) of garbage truck [14]. The M&R system is being improved in the direction of periodicity technical impacts optimization taking into account the technical reliability indices and operating conditions by the criterion of minimum unit costs for maintaining and restoring a state of serviceability [15]. The researchers are conducted to enhance models and methods for developing route schedules garbage trucks with a view to optimize the process of MSW disposal [16-18]. As concerns the MSW collection, the researchers are aimed at improving garbage trucks and grippers designs [19-24].

2. Methods

At present, the engineering design fundamentals of machines for MSW collection and disposal are based on the known positions of theoretical mechanics, theory of strength of materials, theory of mechanisms and machines, and theory of vehicles. The current method for calculating manipulator includes characterization of estimated positions, kinematic and dynamic analysis of system and strength design calculation [25]. The process of MSW collection (loading process of containers in truck body), despite the outrigger availability, is oscillatory type, related to the base vehicle sprung mass. This gives rise to generation of loads of dynamic nature in the manipulator structure elements and the grip, and peak values significantly higher than the estimated, which are currently determined, without considering vehicle frame free oscillations [26].

For the purpose of description and accounting of truck oscillations in operating mode the design scheme, the differential equations of oscillations of vehicle frame and manipulator with container using the Lagrange's equations of the second kind are composed; the dependence of vehicle frame’s oscillation angle in one operational cycle of manipulator is obtained. In order to determine the amplitude-frequency characteristics the equation of manipulator oscillations taking into account vehicle frame oscillations in one operational cycle is developed and the dependence of changes in lifting angle of manipulator in one operational cycle under different loading of body is obtained [27].

The researches on garbage trucks reliability [28] have shown that a substantial proportion of attached implements refusals (≈50%) can be accounted for steel structures and hydraulic system, of which about 80% accrue to the boom, manipulator grip and their drive.

In order to reduce the acting efforts in the grip structural elements, as well as improve its work reliability and prevent deformation of container walls a grip construction is developed [29, 30], which provides picking up under the container bottom.

For determining the loads generated in the grip elements of new design the calculation models are developed (Fig. 1), the equilibrium equations in the «grip-container-grip» system (1, 2) are composed and modeling of efforts in the grip structural elements in one operational cycle of manipulator as a function of the angle of oscillation of the vehicle frame is carried out. The results modeling show that when using the proposed grip design the loads occurring in «grip-container-grip» system diminish in different phases of manipulator operation cycle from 1,2 to 5,5 times in comparison with the serial grip. Maximum loads occur on hydraulic cylinder rods, which increase when rising container weight. The garbage weight change does not affect the value and amplitude of loads, but their frequency response varies only [27].

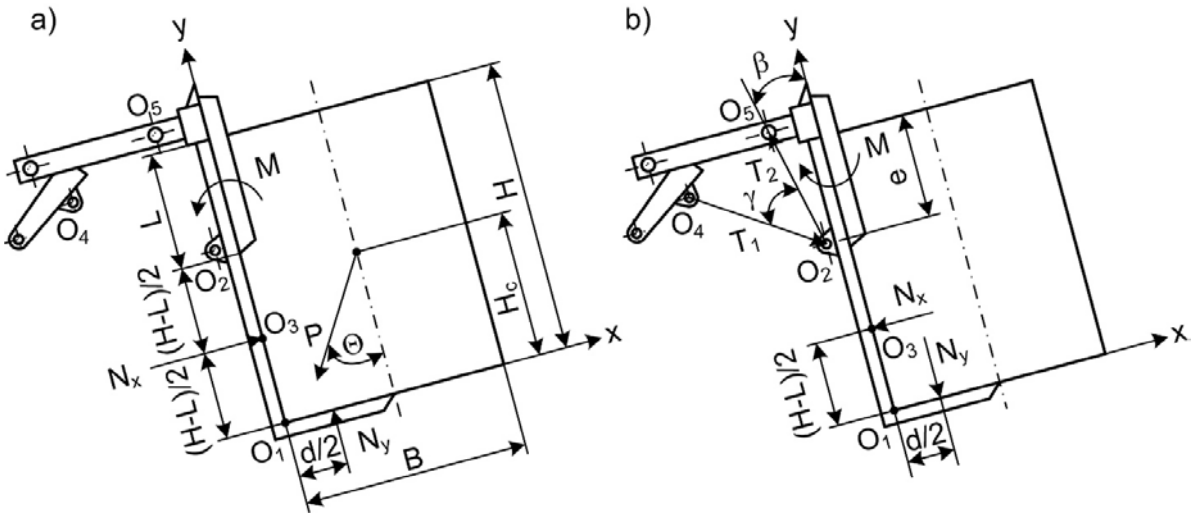

Fig. 1. (a) calculation models of forces in «grip-container-grip» system on the side of grip to container; (b) calculation models of forces in «grip-container-grip» system on the side of container to grip

$$\begin{cases} \sum F_{kx} = 0; \quad N_x - P \cdot \sin\Theta = 0, \\ \sum F_{ky} = 0; \quad N_y - P \cdot \cos\Theta = 0, \\ \sum m_{O_1} = 0; \quad P \cdot \dfrac{B}{2} \cdot \cos\Theta - N_y \cdot \dfrac{d}{2} - P \cdot H_c \cdot \sin\Theta + N_x \cdot \dfrac{H-L}{2} - M = 0. \end{cases} \tag{1}$$

$$\begin{cases} \sum F_{kx} = 0; \quad -N_x - T_2 \cdot \sin\beta + T_1 \cdot \sin(\beta+\gamma) = 0, \\ \sum F_{ky} = 0; \quad -N_y + T_2 \cdot \cos\beta - T_1 \cdot \cos(\beta+\gamma) = 0, \\ \sum m_{O_2} = 0; \quad M + N_x \cdot \left(\dfrac{H+L}{2} - e \right) + N_y \cdot \dfrac{d}{2} = 0, \end{cases} \tag{2}$$

where Nx, Ny – normal pressure on container wall and bottom, respectively, H; P – container weight, H; Θ – manipulator lifting angle, rad; B – container width, m; d – pick-up length at container bottom, m; Nc – height of center of container masses, m; H – container height, m; L – length of grip plate plunged into in a container, m; T1 – effort at hydraulic cylinder rod of clamp, H; T2 – effort at control hydraulic cylinder rod, H; β – inclination angle of control hydraulic cylinder to Y axis, rad; γ – angle between the axes of hydraulic cylinders, rad; e – distance from top edge of container to attachment point of hydraulic cylinders rods, m.

3. Results

The «grip-container-grip» system reliability is not influenced primarily by loads acting in it, but by torque moments. The moment values depend on constructional and mounting dimensions. Considering the H and B container sizes as known, let «e» linear dimension be defined from moment equation of the system (2).

$$e = \frac{B}{2} ctg\Theta + H - H_c \tag{3}$$

In case of constant sizes of a container «e» value is a function of lifting angle of manipulator in one operational cycle. Modeling of «e» parameter under complete garbage truck load shows that according to equilibrium condition of moments many values cannot be realized because they exceed container dimensions for height (Fig. 2,a). After 2,5 seconds of work «e» parameter takes on a value, which corresponds to the level of container bottom. At the end of cycle «e» value is reduced to a value corresponding to height of center of gravity of complete container (Fig. 2,b). It should be noted that on a section from H to H_c «e» values for full and empty garbage trucks differ by less than 1%.

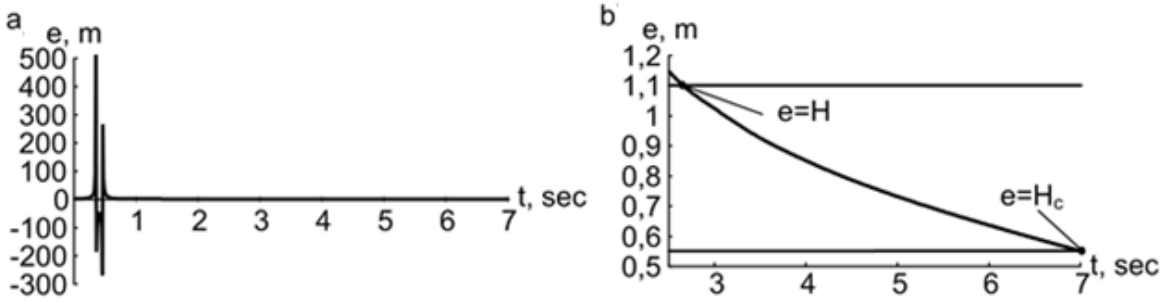

Fig. 2. Distance from top edge of container to attachment point of hydraulic cylinders rods

Modeling of torque moments in «container-grip» system can be carried out as a function of «e» value based on design constraints for maximum values of N_x and N_y, that corresponds to full container loading in full garbage truck (Fig. 3). Minimal moments values occur when the attachment point of hydraulic cylinders rods (O_2) coincides with the application point of force N_x (O_3), that is,

$$e = (H + L)/2 \tag{4}$$

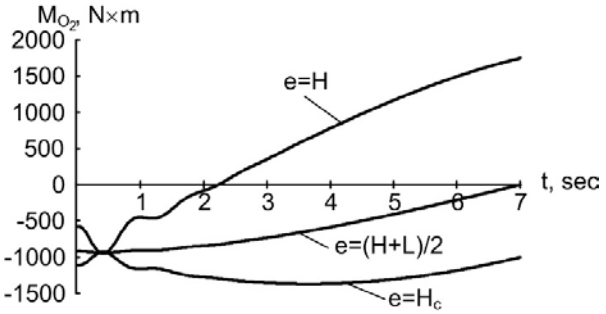

Fig. 3. Torque moment in «container-grip» system

In this case, the torque moment in the system only occurs under the effect of force N_y. With decreasing «e» value the moments are increased and its rise causes in addition the moment to change direction of action during operational cycle.

The «e» value does not only affect the torque values. The angles of inclination of hydraulic cylinders β and γ to the axis Y depend from it. These angles determine the effort values on their rods. The increasing of «e» value leads to a decrease of the angles β and γ, at that, the efforts on rods of hydraulic cylinders T_1 (Fig. 4,a) and T_2 (Fig. 4,b) are increased.

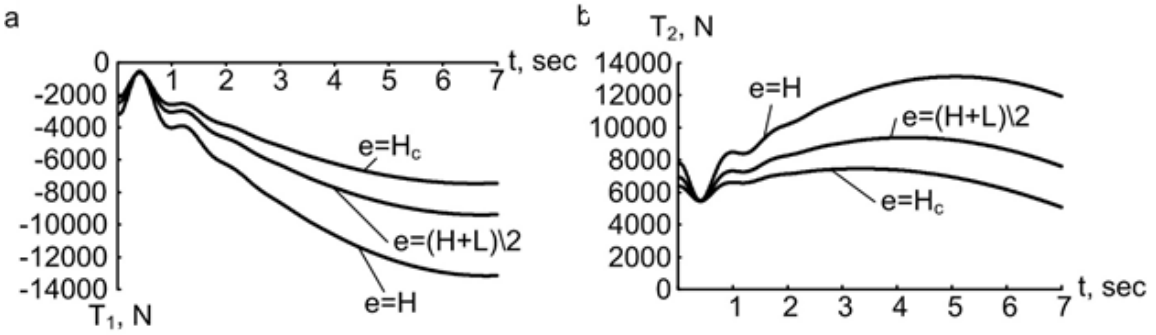

Fig. 4. Efforts at grip hydraulic cylinders

With a view to ensuring in the system «container-grip» the effects of minimum moments and minimum stresses on rods of hydraulic cylinders «e» values must be different when other factors being equal. This condition cannot be satisfied because the attachment point of hydraulic cylinders rods (O_2) cannot structurally change its position during operation. In observance of the conditions of generation of minimum moments, as well as stresses it is necessary to make changes to the layout scheme of grip so that the attachment point of rods of hydraulic cylinders (O_2) has the same height as the attachment point of force N_x (O_3); in addition, it is required to shift the attachment points of casing shells of hydraulic cylinders O_4 and O_5 in the direction of increasing angles β and γ.

The generation of moments in «container-grip» system is influenced by «e» value, as well as by length of the pick-up under the container bottom d. The modeling results (Fig. 3) are obtained on the assumption that d=B/2. Taking into account the condition (4), the equation of the moment becomes

$$M = -N_y \cdot \frac{d}{2} \tag{5}$$

The equation (5) shows that with the increase of d the growth of torque values will occur (Fig. 5,a). For ensuring minimum torque d value should be positive, tend to minimum, but should not be equal to 0, since in this case the grip design and calculation schemes of forces and moments change (as an example d_{min} = 0,05 m).

The length of the pick-up under the bottom of the container d influences the moments generation not only in the «container-grip» system, but also in the «grip-container» system. The estimation of d value influence on generation of a moment bending the container wall can be done by means of the moment equilibrium equation of the system (1). The modeling results show that in the «grip-container» system the growth of a moment occurs when reducing d value (Fig. 5,b). In this respect, for the range of d value variation, except d_{max}, the torque changes the direction of its action during operating cycle of manipulator.

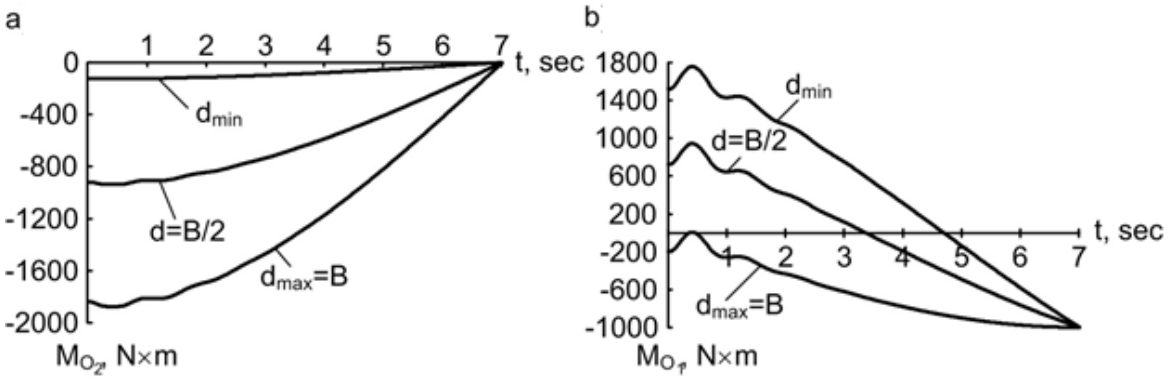

Fig. 5. Torque moments in the «grip-container-grip» system

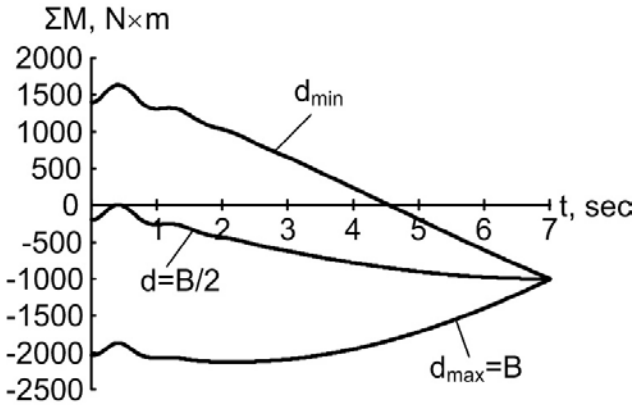

Fig. 6. Sum of moments in the «grip-container-grip» system

The «grip-container-grip» system is influenced by two moments: M_{O1} and M_{O2} that during operating cycle of a manipulator can either counterbalance or amplify the effect of each other (Fig. 6). At d_{max} both moments are in effect in the same direction, amplify the effect of each other and in the system the maximum total moment occurs. At d_{min} at the end of operating cycle of manipulator the system has a minimum total moment, but in the beginning of a cycle its value is close to the maximum, while during the operating cycle the change in the direction of its action occurs. The d=B/2 value is optimal in terms of generation of the total moment, which does not change direction of its effect and takes minimum values for the most part of operating cycle in this case.

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