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Automation of working unit on a bucket loader

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Abstract

For bucket loaders, the anticipated benefits of advanced machine control are increased capacity, decreased energy-consumption and improved safety. However, where dual automatic and manual modes of operation are to be maintained, it is important that the operator needs are taken into account. His level of attention must be above the threshold level of interest. In collaboration with FADROMA Construction Machines, Wroclaw, Poland, the authors have researched, designed, built and tested under both laboratory and site conditions, a bucket loader which can be operated under manual of automatic conditions. It has proved capable of excavating difficult granular materials. This has been achieved by detailed consideration of the motion requirements for excavation.

1. INTRODUCTION

Mobile construction machines, including bucket loaders, after relatively rapid evolution, have assumed a stable form in the recent years as far as their fundamental concept and basic construction-operation indices are concerned. Polish analyses and world trends show that further development of these machines should involve the use of modern techniques, especially microelectronics [1-7]. The main spheres which require the use of automation in the new generation of machines deal mainly with the facilitation of machine control, increased capacity, decreased energy-consumption and improved safety. For some years the Institute of Machine Design and Operations Research has been carrying out research into, and tests on, the automation of mobile construction machines. The article discusses the problems of the control of scooping the bucket of the loader with almost unmineable granular material and positioning of the operation and its duty cycle. It presents an integrated automatic system for controlling these processes, their usability being confirmed by operation tests.

2. SCOOPING OF THE BUCKET

Scooping of the loader bucket with granular rocky material is achieved with two independent movements: rectilinear motion parallel to the base brought about by the driving mechanism of the loader and rotary motion in the plane which is perpendicular to the base, performed with the construction equipment (bucket with an extension arm). In case of the material which is hard to be mined, for instance material of high cohesion or high granulation, the distance to which the bucket is pushed into a dump is restricted by external influence, that is, material resistance and the resistance increases gradually with the increase of the bucket penetration. If the value of resistance equals the maximum disposable value of the loader thrust force, there occurs stoppage of its dislocation, which can happen even at partial penetration of the bucket into the dump. The rotational closing of the bucket leads to small scooping of the bucket with excavated material.

The test showed that improvement in the performance can be obtained, for instance, by using appropriate motion procedures for the bucket consisting of its graduated partial rotation, that is elementary rotations performed in the initial phase of the closing rotation [8]. Due to the elementary rotation of the bucket, thrust and direction in the dump of granular material, the state of inner equilibrium is disturbed, that is there occurs mutual displacement of material grains around its edge and walls, leading to a decrease of the resistance of the centre influencing the bucket.

Under the influence of the thrust force, brought about by the loader, additional penetration of the bucket into the dump is obtained to the value restricted by the renewed resistance increment. The next elementary rotation of the bucket starts the next stage of the process of so called gradual scooping. After a number of stages the scooping process ends with the closing of the bucket. The bucket is scooped in a continuous way with the remaining disposable part of its rotation (fig.1).

Even in the case of granular material with high mining resistance, this way of scooping the bucket makes it possible to thrust the bucket properly into the dump and scoop the bucket with the excavated material after closing (fig.2).

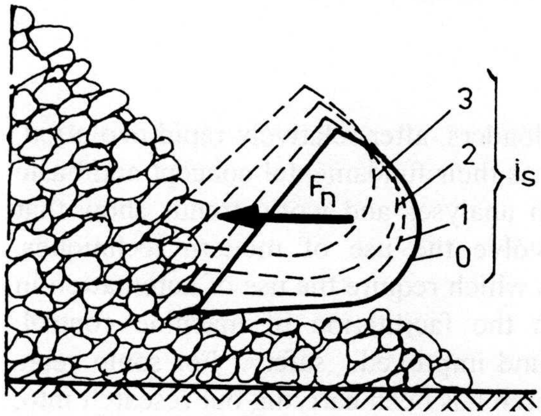

Figure 1. Gradual Scooping of Bucket Loader

i_s = Number of Bucket's Rotation

F_a = Maximum thrust force of a loader

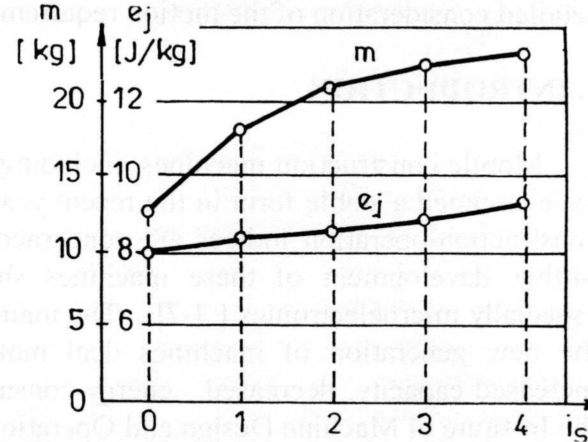

Figure 2. Results of Laboratory Tests

m = Mass of Scooped Material

e_j = Unit energy of scooping the bucket with material

In order to ensure the regularity and optimisation of such a process it is necessary to appropriately select the number and value of the elementary angles of the bucket rotations. The examinations conducted in this field show that the magnitudes of these depend primarily on the type and condition of the mined material. Practically, it was found that they can be in the range: number of degrees $i_s = 2 - 6$, elementary angles of rotation $q = 10° - 4°$ [9].

Detailed investigation of the individual motions of the loader bucket during the scooping process shows that rectilinear motion pushing the bucket into the material dump is achieved by the driving mechanism of the machine in the continuous way without intervention of the machine operator. On the other hand, the bucket rotation during its closing at the bucket scooping, especially at multi-stage scooping, is achieved by successive switching on and off of its drive. Thus, controlling requires some practice, attention and additional effort of the loader operator. The automation of the process was suggested in order to ease the operator physically and psychologically as well as to integrate and optimise the process[10]. Laboratory and field analyses and studies conducted for many years on bucket scooping with granular material, made it possible to put forward a simple system which automates this process with the use of an on-board computer (fig.3).

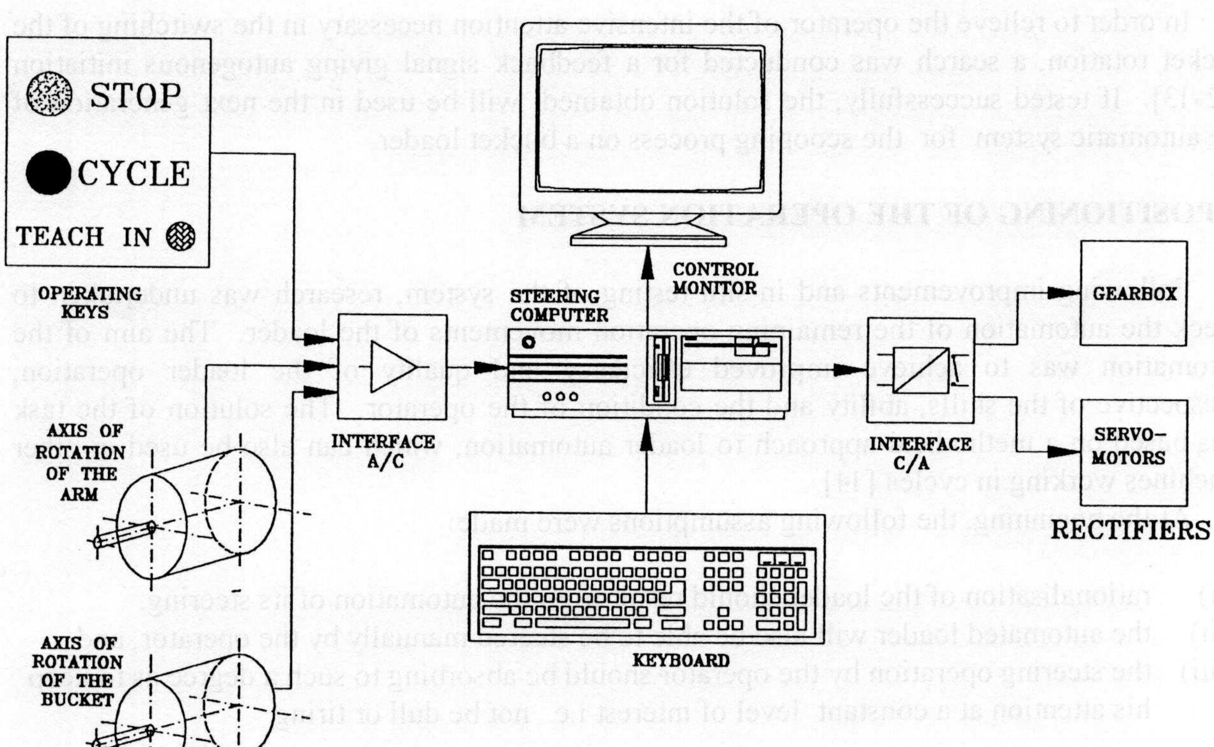

Figure 3. Integrated system of automated working unit on a bucket loader.

The suggested system gives the possibility of regulating wide range in the number of the process degrees, values of the elementary angles of the bucket rotation and the duration of breaks between them, that is the times of bucket penetration into the dump in successive degrees. Thus during the loader operation there are possibilities for the proper selection of these magnitudes according to the type and condition of the loaded material.

The automated system, having been tested under laboratory conditions, was then used in a L220 loader manufactured by FADROMA Construction Machines, Wroclaw, Poland. The results of in situ testing of the system show that it is correct and applicable in practice [11]. High scooping of the bucket with the excavated material and thus high loader efficiency was obtained after the proper selection of the parameters of the multi-stage steering. Comparison of the capacity results obtained for the loader with automatic and manual steering shows that they are similar only when the loader is manually operated by an operator of great skill and practice in machine steering. Such an operator is involved to a great extent both physically and psychically in these operations. Other cases prove the superiority of automatic programmer. In the presented automation system, the first impulse to the bucket rotation after its initial thrust into the material dump is performed manually by the operator. According to these studies, the moment of starting the rotation is significant in the performance of the process. Delay in its starting leads to machine standstill and also long slippage of the road wheels of the loader or the hydrokinetic torque converter and high wear and heat generation. If the rotation is started too early it can lead to incomplete scooping of the bucket in the excavated material.

In order to relieve the operator of the intensive attention necessary in the switching of the bucket rotation, a search was conducted for a feedback signal giving autogenous initiation [12-13]. If tested successfully, the solution obtained will be used in the next generation of the automatic system for the scooping process on a bucket loader.

3. POSITIONING OF THE OPERATION SYSTEM

Following improvements and in-situ testing of the system, research was undertaken to check the automation of the remaining operation movements of the loader. The aim of the automation was to achieve improved efficiency and quality of the loader operation, irrespective of the skills, ability and the condition of the operator. The solution of the task was based on a methodical approach to loader automation, which can also be used in other machines working in cycles [14].

At the beginning, the following assumptions were made:

(i) rationalisation of the loader should result from the automation of its steering,
(ii) the automated loader will also be able to be steered manually by the operator, and
(iii) the steering operation by the operator should be absorbing to such a degree as to keep his attention at a constant level of interest i.e. not be dull or tiring.

The methodical solution of the problem consisted of a detailed analysis of the operational functions of the loader, assigning appropriate steering operations and classifying them using evaluation criteria appropriate to the group of automatically and manually steered ones. The philosophy behind the classification was to obtain a logical sequence of a few, possibly simple, operations for manual steering corresponding to the natural habits of the operator with his attention absorbed in order not to make his work monotonous. In accordance with the aforementioned principles, a detailed analysis of the operational activities of the loader working in a storage yard was conducted (fig.4). On this basis, its basic operation cycle was determined and this divided into successive phases which are attributed appropriate functions for individual mechanisms and respective steering operations.

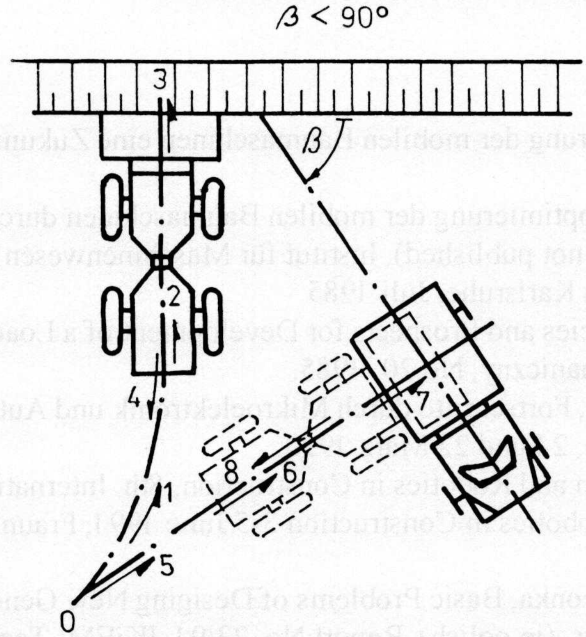

Figure 4. Phases of the typical cycle of bucket loader in operation: 1-access to the scooping place, 2-position to scoop, 3-scooping, 4-withdrawal after scooping, 5-access to the emptying area, 6-position to empty the bucket, 7-emptying, 8-withdrawal after emptying.

The steering operations, in turn, were divided into two groups:

(i) manual steering, simple (e.g. maintaining the driving track change of engine rotations) and those especially important in the operation (e.g. steering the brakes in case of safety requirements).

(ii) automatic steering of the system coupled in such a way that the operator's motion initiating the main operation starts a programmed sequence of steering operations (e.g. steering, positioning of the extension arm and the bucket and gear changing)

On this basis, the system was designed which carried out the above operations. The system was integrated with the automatic scooping system for the bucket (Fig 3.). Thus designed, the automatic steering system and gear box was tested on a L200 Loader manufactured by FMB FADROMA. These tests proved satisfactory. A video record was made which shows the automatic scooping operation on a bucket loader.

CONCLUSION

The solutions which have been discussed here proved satisfactory in the results of operational tests. This inspired the search for still better solutions. Further studies and tests carried out in the Institute of Machine Design and Operation Research, Technical University of Wroclaw of Poland are aimed at designing an intelligent adaptable system of higher generation. Such a system could automatically initiate the optimum kinematics of the working unit (bucket and bucket arm) best suited to the type of scooped material in the process of scooping. Additionally, research is being conducted in order to design an active device on construction machines with articulated frame steer.

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