COMPUTER AIDED DESIGN OF LOADER WORK ATTACHMENT FOR CONSTRUCTION MACHINES

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Abstract: The design of a work attachment for wheel loaders and face-shovel hydraulic excavators using a specialised software is presented in the paper. The software makes the design process easier due to various analyses regarding the kinematic and kinetic characteristics of the work attachment and the machine. The significant feature of the software consists in advanced options of determination loading cases necessary for stress analysis of the load-carrying structure.

Keywords: loader, work attachment, design, software

1. INTRODUCTION

For loading excavated materials into transport vehicles wheel loaders or alternatively excavators with face-shovel work attachment can be used. Wheel loaders can also transport the excavated material over relatively short distance (a couple of hundred of meters).

The work attachment of a wheel loader comprises a boom pivoted to the machine superstructure, a bucket pivoted to the opposite end of the boom and hydraulic cylinders, activating the components (Fig. 1). There are two main types of a linkage system of wheel loader work attachments, i.e. type ‘Z’ and type ‘O’. The main advantage of the type ‘Z’ linkage system is that it requires a smaller diameter bucket cylinder. This is due to greater forces generated by the actuating cylinder during the digging phase.

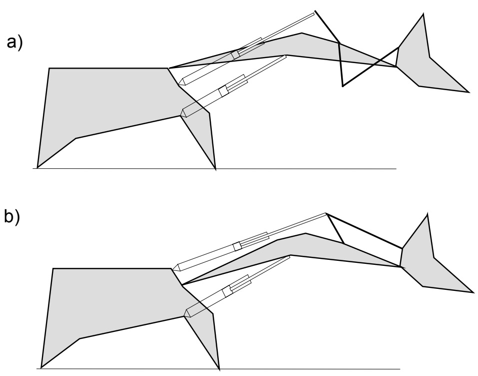

Fig. 1 Linkage systems of wheel loaders: a) type ‘Z’, b) type ‘O’

An excavator with a face-shovel work attachment comprises three main components, i.e. the boom, arm and bucket (Fig. 2). There are several types of the linkage system of this work attachment, two of them will be discussed in the paper. The simplest one is the classic system (type ‘I’), Fig. 2a, in which motion of the main components is independent due to pivoting the hydraulic cylinders on the next components, whereas in the type ‘II’ linkage system the bucket cylinder is pivoted on the boom instead of the arm. Due to this the bucket position depends on the arm position against the boom, hence when the arm moves upwards the bucket turns down and opposite. Such correction of the bucket is necessary to keep it in the same position during levelling. The main advantage of this system is that the operator can more easily load the bucket on the ground level. In more advanced linkage systems an additional hydraulic cylinder is used, which activates the bucket cylinder when the arm moves.

The most advanced linkage system for face-shovel work attachment of hydraulic excavators is the TriPower system of O&K, which allows the bucket to be kept at the same inclination with respect to the ground level during both levelling and lifting.

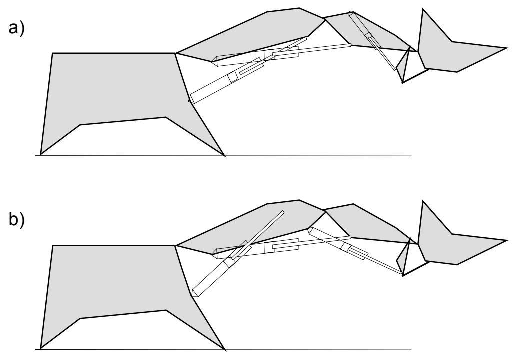

Fig. 2 Linkage systems of excavator loader attachments: a) type ‘I’, b) type ‘II’

For the accurate operation of the machine the linkage system of the work attachment must achieve predefined positions of the boom and bucket as well as induce appropriate digging forces. Design of the linkage system is an iterative process consisting in multiple changes of lengths and diameters of hydraulic cylinders as well as their pivot points on the load-carrying structure of work attachment. To make the design process of work attachments for both wheel loaders and hydraulic excavators easier a software package ROLAD and RODOS have been developed.

2. DESIGN STAGES OF A WORK ATTACHMENT

The work attachment of a wheel loader or an excavator is a unit that significantly affects the quality of the whole machine, since it determines its reliability and productivity. Therefore a great deal of effort is spent on the proper design and manufacturing of the work attachment [1].

The design process of the work attachment is divided into following stages:

- design of the linkage system
- evaluation of the kinetic characteristics of the work attachment
- stress analysis of the load-carrying structure, and
- stability analysis of the machine.

The design begins with the selection of basic dimensions (lengths, defined as distance between pivot points) of the main components of the work attachment. The tilt angles of those components, resulting in a required working range, are obtained via length selection of links and hydraulic cylinders as well as position of pivot points of those components. Altogether they compose the linkage system, consisting of two (or three, for an excavator) driving mechanisms: for the boom, arm and bucket.

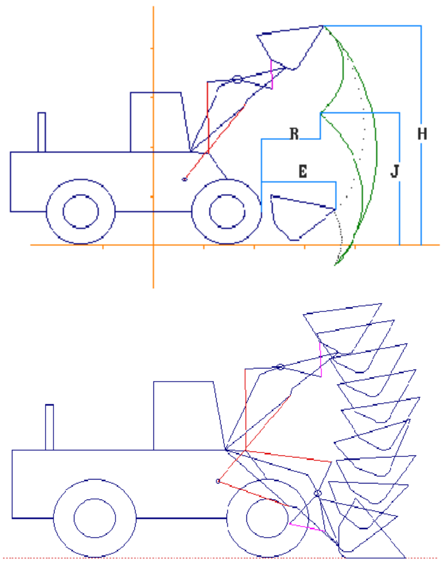

Fig. 3 Examples of kinetic analysis for a wheel loader

A correctly designed linkage system should also ensure the bucket to be kept at the almost constant position (inclination) with respect to the ground level while lifting the bucket with the excavated material without necessity of making any bucket correction. Examples of kinematic analyses obtained using the software ROLAD and RODOS are shown in Fig. 3 and 4 respectively.

As far as an excavator is concerned, the type ‘II’ linkage system of work attachment should also keep the bucket at the almost same inclination with respect to the ground level during levelling (Fig. 4b). This is required without activating the bucket cylinder.

Results of simulation of change of the bucket inclination during lifting for an excavator with a type ‘II’ linkage system is shown in Fig. 4c.

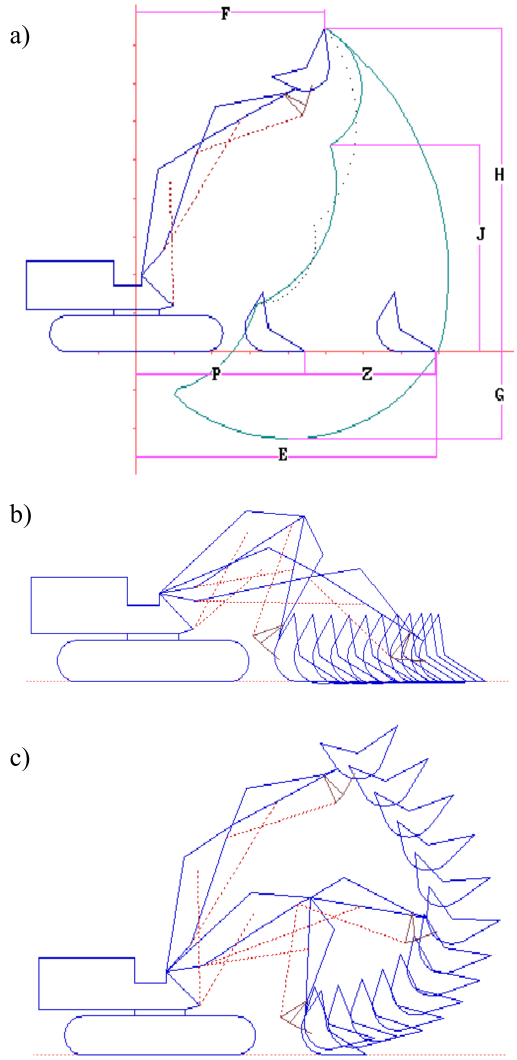

Fig. 4 Examples of kinetic analysis for an excavator with a face-shovel

A more advanced kinematic analysis allows one to study the entire duty cycle, however this requires the diameters of the hydraulic cylinders as well as the hydraulic pump delivery to be known. Those data as well as the hydraulic oil pressure and weight of work attachment components are also required for the assessment of kinetic features of the work attachment.

For a correct machine operation the hydraulic cylinders of the work attachment must be able to generate the assumed magnitudes of forces, necessary for both filling-up the bucket and lifting the boom. Those capabilities can be assessed using different ways.

The first one is by the analysis of oil pressure in the boom cylinder while lifting the work attachment with a full bucket. An example of the analysis for a wheel loader is shown in Fig. 5a, where the change of the relative oil pressure, p/p_{max}, is shown as a function of the boom position, moving from the lower (B2) to the upper (B1) position. The half of the actual pressure is denoted as DP/2-R, whereas DP/2 denotes the fictious pressure, that would be in the boom cylinder if the bucket cylinder would be fixed to the boom instead of the superstructure. Similar diagram for an excavator is shown in Fig. 6a. The third curve in Fig. 5a and the second one in Fig. 6a represent a boom driving moment coefficient K2.

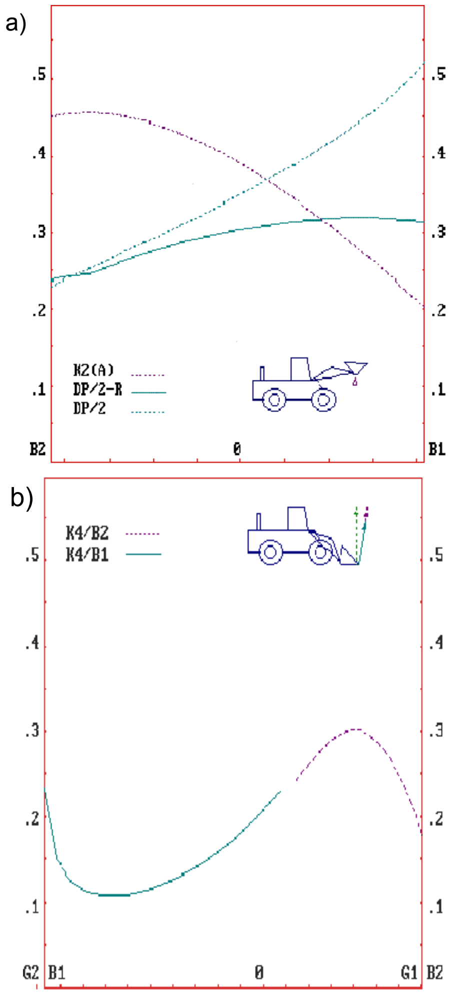

Fig. 5 Examples of kinetic analysis for a wheel loader

The other way to assess the kinetic characteristics of a work attachment is the determination of rated digging forces, defined as maximal values of theoretical digging forces, due to activating the bucket or arm (excavator) or boom (wheel loader) cylinders. The rated digging forces are calculated without taking into account any limitations such as the machine stability, its adhesion to the ground and the interaction between the driving mechanisms of the work attachment.

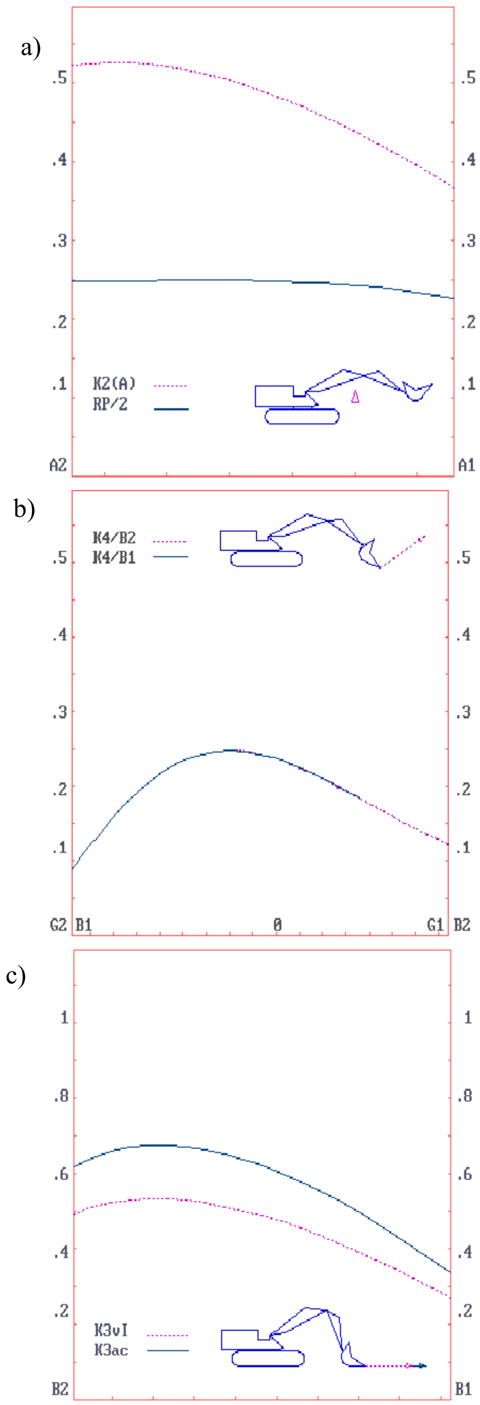

Fig. 6 Examples of kinetic analysis for a an excavator

The forces are presented in Fig. 5b and 6b along with the diagrams of the bucket driving moment coefficient, K4, representing its change as a function of the bucket tilt angle from its lower (G2) to upper (G1) position. It is worth noting that the bucket tilt angles of a loader depend on the boom position, therefore the extreme bucket positions are G2(B1) and G1(B2). The same concerns an excavator with a type ‘II’ linkage system, but the bucket position depends here on the arm position against the boom.

Two different rated digging forces are calculated for a wheel loader:

- the digging force, due to the bucket cylinder, and
- the breakout force, due to the boom cylinder.

The program ROLAD calculates the digging force for two extreme positions of the boom (Fig. 5b). The correctly designed linkage system should achieve a greater value of the digging force for the lower position of the boom.

The rated digging forces for a hydraulic excavator with a face-shovel are following:

- the digging force, due to the bucket cylinder, and
- the horizontal force, due to the arm cylinder.

The program RODOS calculates the maximum value of the digging force (Fig. 6b) and two values of the horizontal force corresponding to the two diagrams of the arm driving moment coefficients K3. One value corresponds to the coefficient K3vI representing the driving moment due to the arm cylinder only, and the second one to the actual value, K3ac, taking into account the reaction in the bucket cylinder. This is to show another advantage of fixing the bucket cylinder on the boom, i.e. increase of the arm driving moment.

The third way of assessing the kinetic characteristics of the work attachment and the whole machine is by using a hodograph of potential digging forces, Fig. 7. The hodograph consists of several hodographs of limit forces corresponding to both driving mechanisms of the linkage system, i.e. of the boom (BM), arm (AM) and bucket (BT) as well as to the machine stability (ST) and adhesion to the ground (FR). A hodograph is a locus of forces’ vertices acting at the bucket cutting edge. Forces shown in Fig. 7a are in fact digging reactions, acting on the bucket, i.e. they are opposite to digging forces. A hodograph of potential digging forces can be calculated for any position of the work attachment. It allows one to assess the kinetic correctness of the work attachment linkage system since it shows all limitations of digging forces.

The digging reactions acting on the bucket cutting edge are the basis for stress analysis of the work attachment load-carrying structure. There are many options of stress and load analysis included into the programs ROLAD and RODOS, allowing a proper design of the work attachment load-carrying structure.

One can only calculate the pivot reactions or stresses in selected points of the boom (and/or arm) as well. The bucket loading can be arbitrarily specified for the analysis or calculated as a potential one, according to rules of the hodograph of potential digging forces (Fig. 8a and 9a).

a)

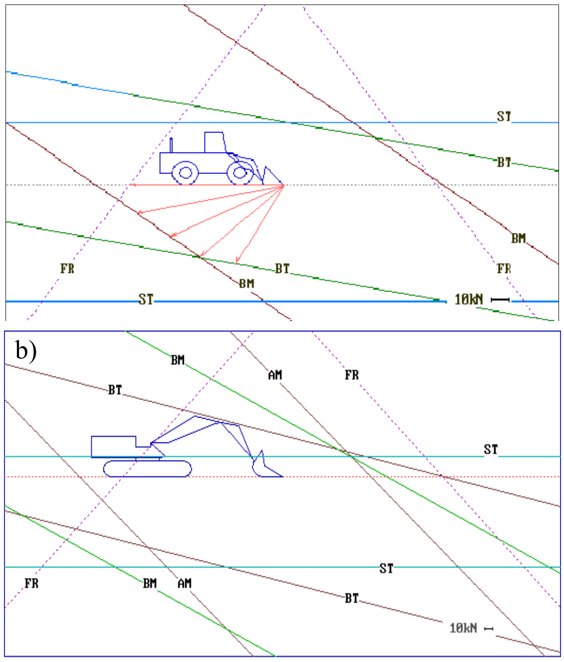

Fig. 7 Hodograph of potential digging forces

It is worth noting that the number of possible positions of the boom, arm and bucket is infinite and the potential bucket loading can differ for each position. Therefore the programs ROLAD and RODOS allow one to predefine the number of the boom and bucket positions and the number of loading cases for each position (Fig. 8b).

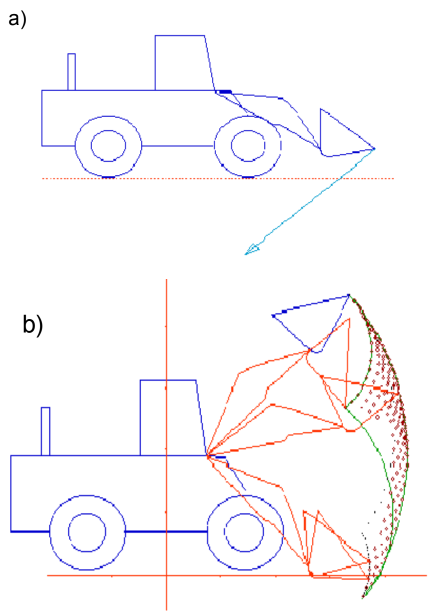

Fig. 8 Strength assessment of the load-carrying structure of a wheel loader

The loading cases and positions of a work attachment for extreme values of stresses (or pivot reactions) are saved and displayed by the end of analysis.

The bucket loading in the stress analysis can be uniformly distributed along the cutting edge or eccentrically applied to its most outer point. This allows one to perform the stress analysis appropriate for both the static strength and resistance against fatigue failure assessments.

a)

b)

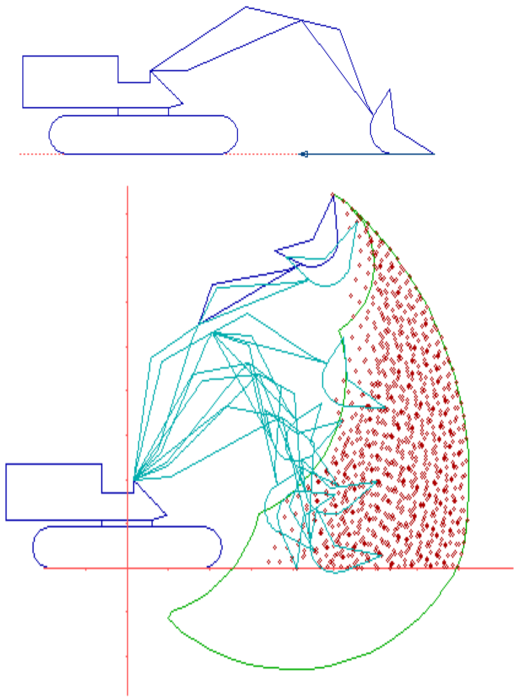

Fig. 9 Strength assessment of the load-carrying structure of an excavator

Due to those capabilities of the programs ROLAD and RODOS it is possible to either roughly design the load-carrying structure of the work attachment or to get an accurate information regarding the loading cases for more advanced stress analysis using FEM, which can be therefore shorter and more effective.

The programs allow one to perform also the machine stability analysis according to specified code requirements. For excavators with face-shovel work attachment it is also possible to calculate the rated lift capacity. The stability analysis is the last stage of the design process of the work attachment, since it can be performed if the weights of its components are known fairly well, i.e. the stress analysis of the load-carrying structure has been done and all its dimensions are known.

3. SUMMARY

The design process of loader work attachments for wheel loaders and excavators is rather complicated and requires a computer aid. The presented software ROLAD and RODOS can be used as a specialised tools for that purpose. They allow one to easily design the linkage system of the work attachment as well as perform various analyses, necessary to assess its various features and to determine characteristics important for comparison with those of the competitive machines.

Various options of the stress analysis allow one a quick but accurate determination of loading cases of the work attachment load-carrying structure. This allows a raw design of the boom, arm and bucket, which can be refined later on the basis of the stress analysis made using more advanced methods like FEM or BEM.

REFERENCES

[1] Dudczak, A.: Excavators: Theory and Design, PWN, Warsaw, 2000 (in Polish)