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MEASUREMENT AND ANALYSIS OF RESULTS AT DIGGING WHEEL EXCAVATOR

MĚŘENÍ A ANALÝZA VÝSLEDKŮ MĚŘENÍ NA KOLESOVÉM RYPADLE

Abstract

Longitudinal measurements are in process within program MPO FT-TA2/008 and they are called "Verified progresses of technical lifetime determination within dynamic loading equipment" and MPO FT-TA4/0078 "Modern trends of increasing of equipment reliability for open-cast mining of utility minerals",. ÚAM Brno, s.r.o. is the program holder and it cooperates with VŠB-TU in Ostrava and VÚHU in Most in the field of many measurements. The aim of these measurements (input power of the wheel, measuring and distributed forces, efficiency, power vibrations of the wheel etc.) is not only arrangement of the whole measuring system but mainly verification of relations – measured vibrations of key power units is consequently both the indicator of its technical state and the loading indicator of these power units and key constructional points of large.

Abstrakt

V rámci programu MPO FT-TA2/008 o názvu „Verifikované postupy stanovení technického života dynamicky zatěžovaných zařízení"a MPO FT-TA4/0078 "Moderní trendy zvyšování spolehlivosti zařízení pro povrchovou těžbu užitkových nerostů", jehož nositelem je ÚAM Brno, s.r.o., probíhali a probíhají dlouhodobá měření, jejichž součástí je celá řada měření, jež provádí VŠB-TU Ostrava ve spolupráci s VÚHU Most. Cílem těchto měření (příkon kolesa, měrné a rozpojovací síly, výkonnost, vibrace pohonu kolesa, atd.) je nejen zajištění komplexního měřícího řetězce ke splnění cílů projektu, ale především ověření souvislostí, že naměřená velikost mohutnosti vibrací klíčových pohonných jednotek je pak nejen indikátorem jejich technického stavu, ale také indikátorem zátěže těchto pohonných jednotek a klíčových konstrukčních uzlů velkostroje.

1 INTRODUCTION

The digging wheel excavators have been reconstructed recently, because their final stage of the original service life is beginning. Moreover, the mining conditions have been changing very much for last thirty years. Just in this time, there is an opportunity to unit the progressive reconstruction and modernization of the digging wheel excavators with increasing of their value in use. This process may be achieved with solution of particular connections and relations between the service reliability and loading of the power units.

The basic idea of the suggested project is the multiple using (multi-using) of the technical and financial acceptable measurements within vibrations sizes of the main power units of the digging wheel excavators (power of the wheel, power of the upper turn). The purpose is to gain their loading diagram (file), actually to gain a database showing the service conditions (work technology and physically mechanical parameters of the mining raw material.), which are based on in-situ measurement.

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The measured size of vibrations within chosen power units is consequently the indicator of both their technical state and loading of these power units.

The entity of solution is the verification and application of the mathematical relation, which expresses the connection between the measured vibrations size within rotary power units and the torsional moment of these units. Then, the torsional moment size enables to make the loading diagram in the time period. This diagram is the core of the database for loadings within chosen constructional and service conditions.

2 THE METHODOLOGY AND VERIFICATION OF THE EXPERIMENTAL MEASUREMENTS PROGRESS AND THEIR WORKING

The verification of the mentioned idea was made with in-situ measurement within the digging wheel excavator KU 800 before and after the reconstruction of the wheel power (more in [1]). The digging wheel excavators was used to verify the methodology only, because measurement before and after was possible. Moreover, it was ready for the diagnostic measurements.

The measured characteristic value was the effective size of vibrations speed v_{ef} [$mm.s^{-1}$] in vertical direction (V – across the electric motor axis), horizontal direction (H – across the electric motor axis) and axial (A – in the electric motor axis). The measurement was made during common mining of the bench.

2.1 The working of measured results

In order to fulfil the aims of the project usefully, the working of the measured file followed this basic progress:

- The measured sizes of wheel power vibrations, ie. v_{ef} = f (f[Hz]), have to be worked in the way, that the dependence $v_{ef} = f(M_k)$ may be used. It means to calculate the torsional moment M_{kvyp} within the chosen power units.

$$v_{ef} = \frac{A}{I}\int_0^t M_{kvyp} \cdot dt \tag{1}$$

$$M_{kvyp} \cdot dt = \frac{I}{A} \cdot dv_{ef} \tag{2}$$

$$M_{kvyp} = \frac{I}{A} \cdot \frac{dv_{ef}}{dt} = \frac{I}{A} \cdot a \tag{3}$$

  v_{ef} = effective speed of vibrations [$m.s^{-1}$]; M_{kvyp} = torsional moment [N.m]; I – moment of inertia within the rotary object [$kg.m^2$]; A – deflection amplitude of vibrations calculated from vibrations spectrum [m] and t - time [s].

- To make the comparison of the sizes - measured torsional moment (Mkměř) with size of the torsional moment calculated from measured vibrations size of power units (Mkvyp) including the difference determination, which enables to determine the verification of the relation for (Mkvyp).

- The working of the loading diagram of the chosen power units in the time period
  - $M_{kvyp} = f(t)$
  - $M_{kměř} = f(t)$

  and the evaluation process. This progress verified the suggested methodology and the correspondence of measured values was found out, not their absolute sizes.

3 THE MEASUREMENT AND ANALYSIS OF THE LONG-TERM MEAS UREMENTS WITHIN THE LARGE MACHINES – A DIGGING WHEEL EXCAVATOR K 2000

In accordance with reconstruction projects and newly designed large machines, all measurements were made within the digging wheel excavator K 2000. Moreover, to fulfil the aims of the grant, the measurements were made in the same time period both at VŠB – TU in Ostrava and ÚAM, s.r.o. in Brno.

3.1 The measurement and evaluation in 2006

VŠB – TU in Ostrava made the measurements, which corresponds with mining conditions and they are necessary to be done to fulfil the verifying and other progresses. This is the measurements file:

- Measurement and evaluation of the wheel power input,
- Measurement and evaluation of measured digging and breaking forces,
- Evaluation of efficiency from conveyer scales,
- Measurement and evaluation of lumpiness,
- Sampling of raw material, physical and chemical-petrographic tests including the determination of strength in basic pressure.

This measurement was made, as mentioned above, in the same time period in order to make observations and relations. The results are stated and evaluated in [2].

3.1.1 The evaluation of measured vibrations within the wheel power

As it is mentioned in [2], the necessary incoming condition for the evaluation of vibrations measurements and the torsional moment is the calculation of frequencies within the bearings of power wheel gearbox. These frequencies are stated in [3].

Another necessary step to fulfil the project aims is the determination of moment of force within the wheel bucket, consequently added with the moment of force of the gearbox and the electrical motors of the wheel power. As it is mentioned in [2], the original calculation does not exist, so that the model projection had to be done with kindly help of wheel power gearbox supplier – MKV, s.r.o. in Plzeň. The outputs are in [3].

The relation in the previous chapter was originally designed for powers DPD (long distance belt transport) and it had to be redesigned for the wheel power:

$$M_{k_{vyp}} = I \cdot \frac{a_{ef}}{A_{ef}} \tag{4}$$

It means using the effective value of vibrations acceleration in the place of measurement (a_{ef}) and the effective aberration of vibrations in the place of measurement (A_{ef}). Then, it means to measure aberration and acceleration of vibrations simultaneously, which was approved separate measurement, when we helped ourselves with a measurement equipment of Brüel & Kjær Company, which belongs to VÚHU a.s. in Most and which was used for all measurements.

The calculation of the torsional moment from the vibrations of the wheel power is possible in following ways:

- Direct method

  In the place, where we know the loading moment of inertia of rotary stuff, we measure simultaneously sizes of acceleration and aberration of vibrations and these values are added to the relation

$$M_{k_{vyp}} = I \cdot \frac{a_{ef}}{A_{ef}} \tag{5}$$

- Indirect method with instrument Microlog CMVA60
  - we find out the real motor speed,
  - we set up the Microlog instrument - referential speed for spectrum scanning and in the place, where we recognize the loading moment of inertia of rotary stuff, we measure the effective values of acceleration,
  - we calculate the effective aberration value with the transformational relations,
  - we add the calculated values into the relation.

It is necessary to realize, that the rotary machine objects (constructional places and their particular elements) are valid from the theory of vibrodiagnostics for the progress of vibration sizes within the chosen local frequency. It is so-called "Bath Curve" in the process of operational life of the measured object. The curve characterizes the development of the technical state or wearing. These characteristics are valid for the objects working in relatively steady service condition, however this is not our case, because the powers of wheels work in the wide range of loading values (power, speed, e.g. during our measurement on 1st August 2008, the wheel power worked on the frequency of power electric motor - 96%, ie. 1 147 min^{-1} and f = 19,11 Hz). Consequently, we should think about the existence of the bath curves for various levels of loading within the observed constructional point, ie. the development of wearing will be different for each loading level and then it will approve the mutual determination of the wearing and the torsional moment.

Following classification of measured data of vibrations into various loading levels and determination of the average within each loading level demonstrated the results. We may say, that the correlation and comparison between M_{kvyp} and $M_{kměř}$ showed very nice result.

3.2 Measurement and evaluation in 2007

The evaluation of provided measurements went on in 2007 in order to fulfil the aims of the project. Also, some additional measurements were made, see in [3]. No dangerous aspects appeared from the technical point of view (limit values of vibrations on particular local frequencies). We did not mention any alarm values according to the ČSN ISO 10816-3 or alarm values used at VÚHU, a.s. Most.

The aim of the project and the grant part of the project was to find out the dependence and relation among the torsional Mk, which was measured with the direct method of tensimetrics on the wheel shaft of the digging wheel excavator K 2000 (M_{ktenz}), the indirect way from the input and electric motor speed of the wheel power and finally the calculation with measured vibrations of the wheel power (M_{kvyp}). The progress is mentioned in [1] and [2].

If we follow the classic way, ie, with no attention to speed values and wheel power input, we will come up with the conclusions mentioned in [2]. In this case, we do not respect the division to particular loading levels.

If we respect the conclusions in [2], we will come up with results mentioned in [3] (when power division into several loading levels).

For other verification of measurement results we used the evaluation of measurement, which was made on 14th June 2006, when it was measured M_{ktenz}, $M_{kpříkon}$ a $M_{kvibrací}$ in the same time period. M_{ktenz} measurement was made by ÚAM Brno and the time process was chosen from the detector 33 in the time period 12.54 – 13.54. The sizes of wheel input from graphs K 2000 were added to previous values in chosen times – the complex measurement (mining bench I and II, picture 1 – VÚHU Most). The relation between M_{ktenz} and the input of wheel power was set up on the base of the data analysis. Simultaneously, measured vibrations on the electric motor shaft were transferred to the wheel shaft, because there is better expressive potential to compare with results of tensometric torsional moment measurement (M_{ktenz}). Also, the integration of vibrations acceleration on vibrations aberration was made, which calls for relation in [4] for the measurement M_{kvyp}. It was made within the authorized software of the SKF company, which is distributed together with MICROLOG CVMA 60.

Calculation of M_{kvyp} in [2], then it is valid:

$$\varepsilon_{ef} = \frac{a_{ef}}{A_{ef}} = \frac{M_K}{I} \tag{6}$$

when maximal coefficient of overloading k = 1.6, maximal speed of wheel n_K = 6 min^{-1} and power efficiency η = 0,9. Then, we may calculate M_{kmax} = 4 638 kNm during the loading moment of inertia, which is reduced on the wheel shaft I = 4 742 258 kgm^2, ie.

$$\varepsilon_{efmax} = \frac{4638000}{4742258} = 0{,}978 \tag{7}$$

and it is clear, that only M_{kmax} = 4 157 kNm is logical and furthermore ε_{efmax} = 0,65. Now it is obvious, that data, which did not belong to the interval of the rotary acceleration, was expelled from other analysis because of measurement errors. The results are shown on pictures 2 and 3.

Following regression analysis determined the relation between the characteristic quantity of power vibrations – rotary acceleration of vibrations (ε) and the tensometric measured moment (M_{ktenz})

$$M_K = 0,66\ I_{red}\ \varepsilon_{ef} + 565,88\ [kNm;\ kgm^{-2};\ s^{-2}]. \tag{8}$$

Correlation coefficient R^2 = 0.5128, when the value 565.88 is equal approx. 15% of the installed input and it is very difficult to find out this value from the measurements problems point of view.

- ❑ Evaluation of other relations
  - ▪ PCK = f (Mktenz) – relation the input and tenzometric torsional moment.

    P_{CK} = 0, 7673 . M_{ktenz} + 118 [kW; kNm] (9)

    With correlation coefficient R^2 = 0.7903, when the value 118 is the input of the wheel in neutral state. We can see this relation in the chart on the picture 4 and 5.
  - ▪ PCK = f (Q) – relation of the input with the efficiency
    The values of the efficiency [m³] for the input [kW], were deducted from the graphs on picture 1 (measurement of the VÚHU Most), then the regression came up (Picture 6).

4 CONCLUSION

VŠB – TU in Ostrava concentrated on the partial part of the grant project – verification and determination of relations and dependences between the simply measured parameters and service-important parameters, ie. their multiple using.

- ❑ Logically, when it is possible to regulate the speed of the wheel power, then the input changes too. It means, is not possible to compare the incomparable. Therefore, it is necessary to divide the stuff into the loading levels to get the real results or the bath curves, which are obligatory to determine the technical condition of the object. Moreover, the results require even more detailed division according to the input (approx. 100 kW). Of course, we are aware, that the file of measurements is not very evidential. Four measurements cannot be evidential enough, although it is true, that the vibrations could be measured separately (it was done twice, other two measurements were complex), but the condition of the project was to measure completely in the same time period. The in-situ measurement requires much money, it is very difficult from the technological point of view and it is necessary to measure during the non-productive moment, it means no mining.

- The most valuable outcome is the verification of the formula for the calculation of the torsional moment within the wheel power and its´ measured vibrations with the tensometric measured and input determined torsional moment. Graphs shows perfectly:
  - There is uncompromising dependence between the torsional moment, which is measured tensometricaly from the input, and vibrations of process, not the absolute size
  - The relations are mathematically expressive easily. We used the simplest regression analysis for their determination, because supposed better and more sophisticated ways of measurement as pointless. Moreover, the simple process showed what was demanded.
  - Generally, the progress between the torsional moment acquired form vibrations and tenzometrical way is the same. Considering the input, it is higher in the absolute sizes.
  - Totally equal – the process of the torsional moment from vibrations and tensometrical during higher torsional moments
- The relation was approved – the process of the input of the wheel power and the process of the torsional moment determined tensometrically
- The relation was approved – the input of the wheel power and the efficiency

Finally, we may say, that the measured vibrations and input of the wheel power, which is simple and cheap, could be used for prediction of loading on the wheel shaft and efficiency. It means, that the solution of optimization of the service in real operating conditions may be used as well as the definition of loading conditions for new designed machines.

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Recenzent:
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FIGURES

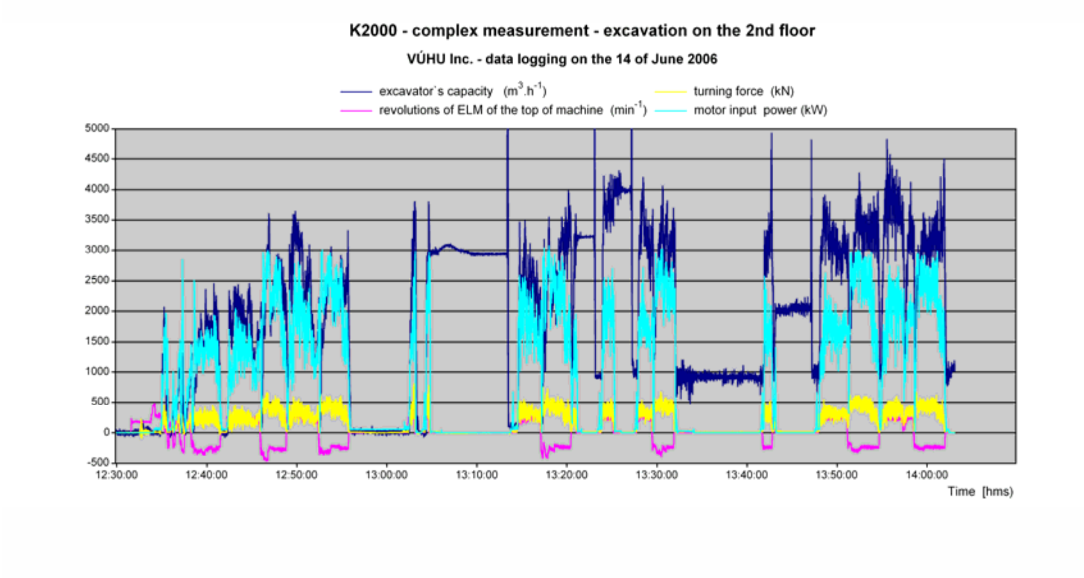

Figure 1

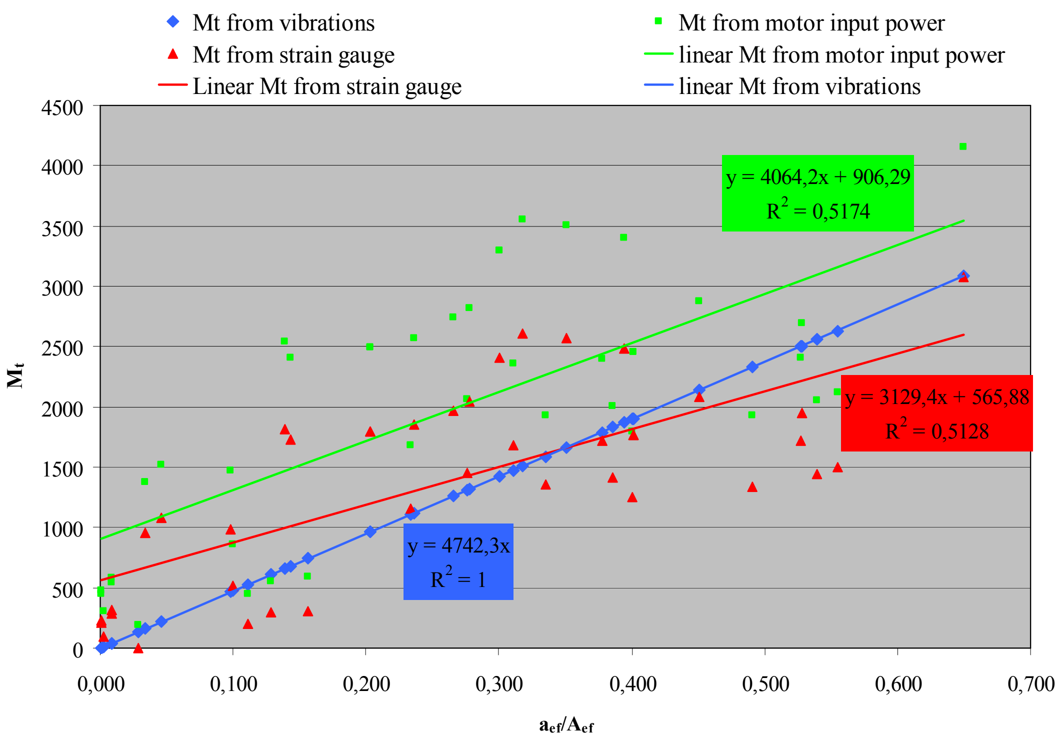

Figure 2

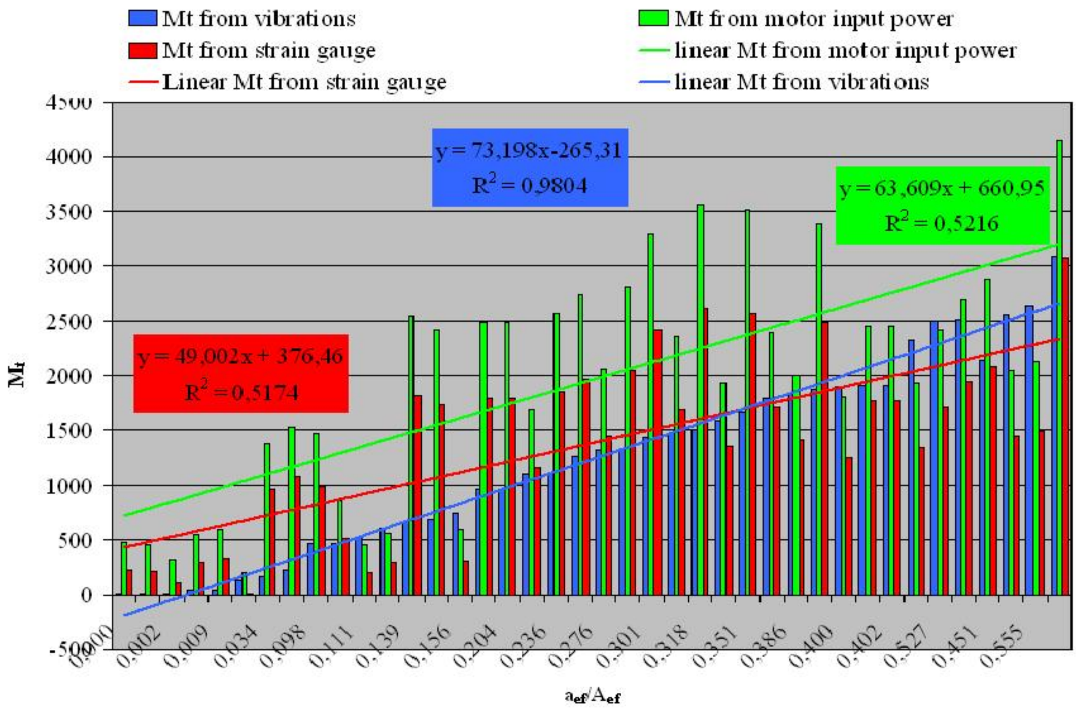

Figure 3

Data regression – data on the 14 of June 2006

M_t – UAM *[kNm]*	***Input- RMS*** *[kW]*	***Input –medium*** *[kW]*	***Input = f(M_t)*** *[kW]*	***Time of data taking*** *[hms]*
2100	1689	1659	2008	13:01:35
3750	2850	2840	3548	13:01:32
2700	1992	1904	2328	13:19:30
3100	2480	2448	3037	13:16:35
3750	2851	2850	3561	13:16:19
2400	2297	2184	2693	13:53:00
3100	2786	2781	3471	13:51:07
3200	2819	2817	3518	13:50:49

Figure 4

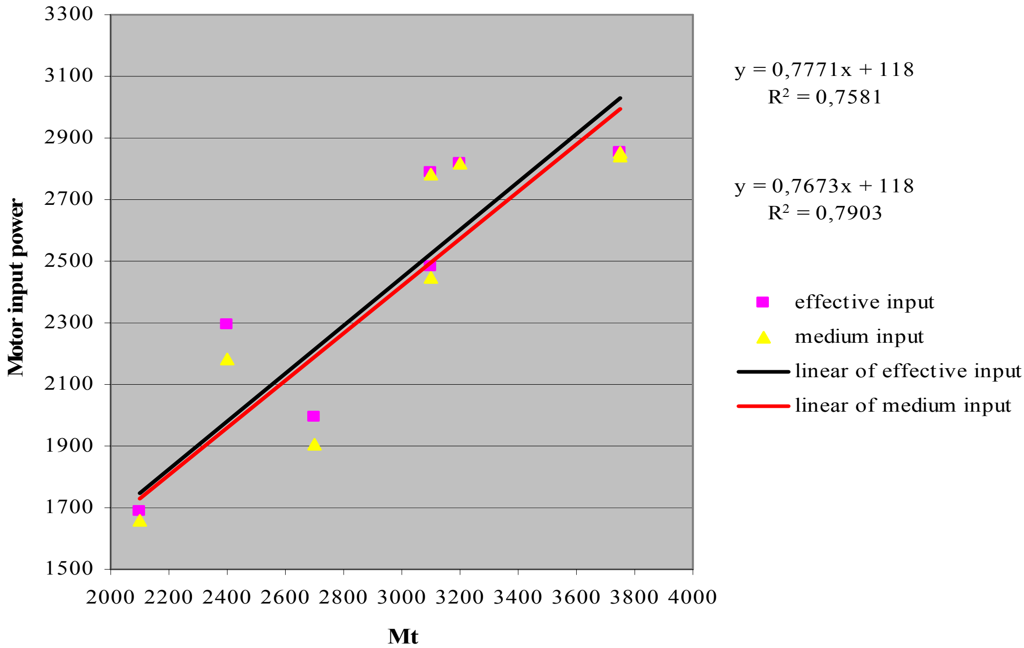

Figure 5

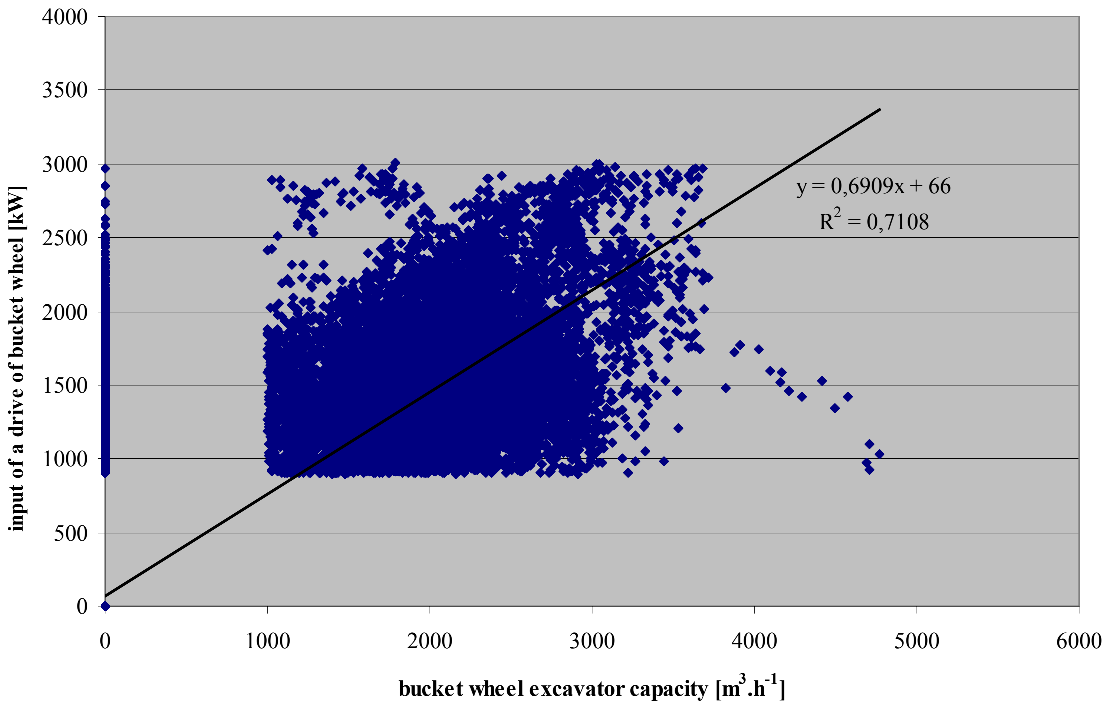

Figure 6