RESEARCH ARTICLE OPEN ACCESS

Forces and Bending Moments in a Ram Press BP30

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ABSTRACT
In this paper the experimental setup, the equipment used, the location of the strain gauges, the experimental results and the analysis of forces and moments acting upon a ram press machine BP30 are presented and analyzed. The data are obtained under operating conditions when sunflower seeds are crashed and oil is expressed. The results for forces and moments are estimated and analyzed to acquire their average maximum values. By using the data for the maximum forces and maximum bending moments acting on connecting rods the coefficient of kinetic friction is calculated to be 0.0718. It is found that the value of this coefficient agrees with the values listed in the literature for lubricated steel on steel contact surfaces. It is concluded that the results obtained in this study could be used for a subsequent analysis regarding the energy losses and energy balance in the machine. Based on that analysis the mechanical efficiency may also be determined and comparison analysis with other designs of ram presses can be conducted.
Keywords - coefficient of kinetic friction, forces, moments, torques, ram press machine, strain gauges.

I. INTRODUCTION

Much of the population of Sub-Saharan Africa suffers from malnutrition. It is often linked to a lack of fat in people's diet. Dietary fats enable the human body to absorb certain vitamins, proteins, and other nutrients. The countries with the lowest consumption of dietary fat tend also to have low GNP and are largely rural population with low-input agriculture. Although most of these countries produce some varieties of oilseed, local processing of seeds is normally insufficient to satisfy the needs. Introducing small-scale processing equipment in rural areas improves the nutritional levels of both people and livestock by supplying necessary dietary fat. Oil production can also increase farmers' incomes, create small enterprises and employment for farmers and oilseed press operators [1]. There are five commonly applied technologies for extracting edible oil from oil-bearing seeds. These include solvent method, screw expellers, oil-plate presses, ram press machines and indigenous (traditional) method. The first two methods are appropriate for industrial applications and have efficiency ranging from 80 to 100%. All these technologies have been applied in Eastern and Southern Africa for oil bearing seeds including cottonseed, soybean, sunflower and groundnuts. The ram press technology is with no doubt the most useful for small-scale rural applications as per references [1, 2]. The method is based on a manually operated machine allowing continuous feed of seeds and nonstop pressing. It is less efficient than the industrial methods but appropriate for small-scale rural application. Indigenous methods on the other hand are non-efficient and are very laborious and lengthy [3].

II. RAM PRESS MACHINE

Several features of the ram press technology are particularly appropriate for the use in rural areas. These are its simplicity, low capital cost and its low requirements in respect of skilled management and maintenance personnel are all significantly important for the rural environment [1, 3].

The BP 30 ram press machine considered in this paper is shown schematically in Fig. 1 and pictorially in Fig. 2. It operates by applying high pressure to seeds placed inside a cylinder and a crashing cage by means of a long piston (ram) driven by a slider crank mechanism. Under high pressure the seeds release part of their oil, which flows out through longitudinal slots of the cage and the cake is enforced to leave at the other end of the cage passing around a restriction cone controlling the pressure in the cage.

The process of expressing oil can be summarized as follows.

- When the handle is raised to its top-dead-position (TDP), the piston is retracted to its right-dead-position (RDP) allowing seeds to drop from the hopper into the cylinder.
- Next the piston is moved forward when the handle is lowered pushing the seeds into the cage under an increasing pressure. When the pressure is raised high enough, about 15-20 MPa [4], seeds are crashed, oil is squeezed out of the cake and drips from the cage gaps into a tray from where it is collected in a bucket.
- Simultaneously the cake is extruded from the opposite end of the cage passing around a restrictor cone and is released out of the cage. The pressure in the crushing cage is controlled by varying the relative position of the restrictor cone with respect to the end port of the cage.

Finally the handle is turned down to its bottom-dead-position (BDP), forcing the piston to reach its left-dead position thus generating maximum pressure in the cage. Usually at this position the piston is left for 1-2 seconds to allow more oil to drip from the cake and therefore increasing the amount of oil being expressed.

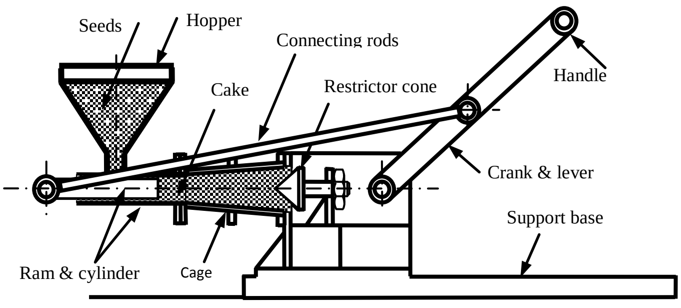
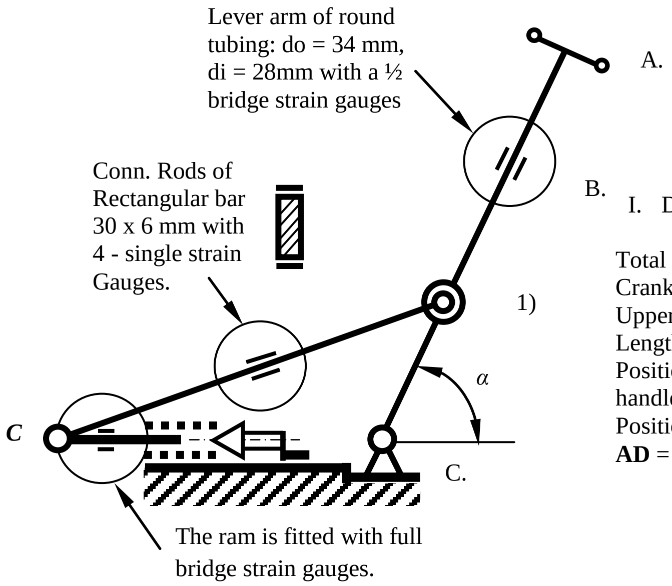


Fig. 1 Schematic illustration of the ram press machine

Fig. 2 The picture of ram press machine



I. Dimensions of the Ram Press, [mm]

Total length of Lever **OB** = 1010,
Crank Radius **OA** = 55,
Upper Lever **AB** = 955,
Length of Connecting rods **AC** = 505,
Position of strain gauges below from the handle **B** **DB** = 395,
Position of strain gauges from pin **A**
AD = 558; d ram = 30 and d pins = 32.

Fig. 3 Positions of strain gauges as installed on the BP30 ram press machine

III. MEASUREMENTS ARRANGEMENTS

The data of experiments are collected during a real pressing of sunflower seeds representing the commonest application of the machine in recent years. Figure 1 shows schematically the essential components of the ram press BP30, while Figs. 3, 4, 5 and Fig. 6 indicate the exact locations of strain gauges installed on the machine components [5].

In order to measure forces generated under operating conditions, electrical resistance strain gauges are attached as shown in Figs. 3, 4, 5 and 7 in the following order and type of bridges used:

- To the piston-1 near its end bearing, a four-gauge bridge is installed (Figs. 3, 4 and 6),
- To the lever-3, which forms the crank of the slider-crank mechanism and carries the handle, (Figs. 3 and 4), a half-gauge bridge,
- To the top and bottom surface of the pair of connecting rods-2 (Fig. 4 and Fig.6), wired as separate active gauges, each having its own dummy gauge to obtain four independent data channels.
- An additional signal, for the position of the lever, is obtained from an angle-of-rotation digital sensor-4 mounted coaxially to the fixed pivot of rotation of the lever 3, (Figs. 4 & 5).

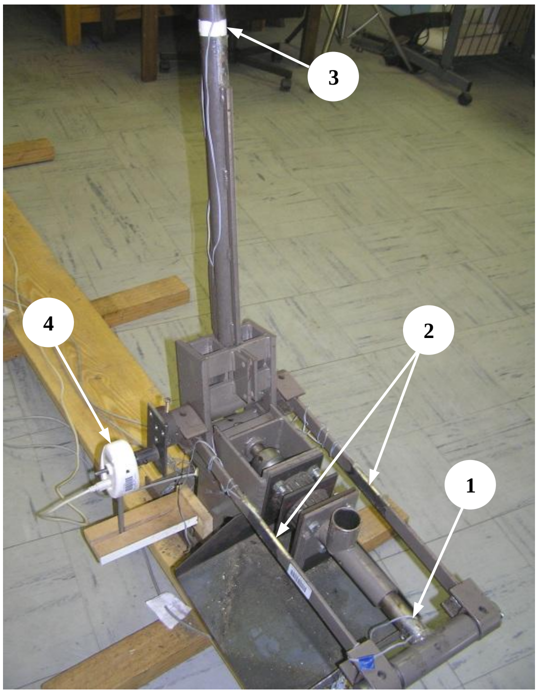


Fig. 4 Arrangement of the sensors: 1 - full bridge on the piston, 2 - two gauges on each of the connecting rods, 3 - ½ bridge on the lever and 4 - the position angle digital sensor.

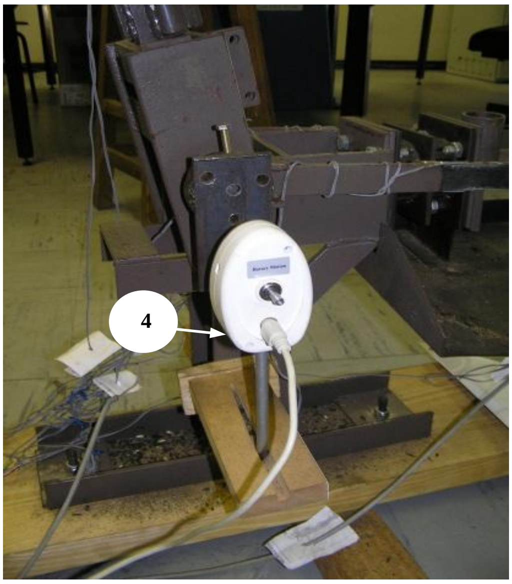


Fig. 5 Position angle digital sensor – 4.

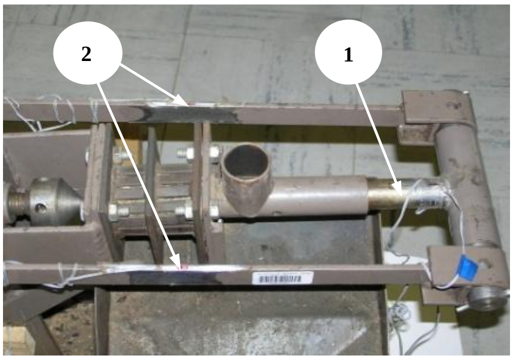


Fig. 6 Full bridge electrical strain gauges bonded at the end of piston (ram) - 1 and two strain gauges attached to each of the connecting rods - 2.

IV. INSTRUMENT SYSTEM

Figure 7 shows schematically the instrument system employed to measure forces and moments as per reference [5]. Signals from the transducers are sampled in a cycle of nine data channels. In addition to the seven channels described above for forces, moments, and position sensing, an additional two more channels are employed: (a) synchronization signal and (b) temperature data from a thermocouple. A combined data logger and signal conditioner (TML type TDS 302) is used for the six strain bridges and for the signals from (a) and (b). Simultaneously, the synchronization signal (a) and the position signal (b) are captured using a data harvest portable data logger, supplied together with a signal conditioning module that is matched to the rotation sensor. The data harvest data logger is used in the interface mode only, so that the data is stored directly on a desktop computer. The sample interval for the TML data logger is determined by a software (TML 7300E) running on the same desktop computer, which limits the capture speed to one data cycle per second. In order to increase the capture speed the data harvest data logger capture rate is set to one cycle per half a second.

Captured data are transferred to a spreadsheet format in order to combine and align the two stored data files, to convert the rotation signal to an angle and the micro-strain figures to a force and moment units. Although the data acquisition software is generally easy to use, the imposed best choice of sample rate is definitely slow in comparison to normal speed of operation of the ram press. For this reason, the ram press is operated slowly during the experiments than its usual performance speed.

The signal from the position angle sensor is recorded in the computer as an incremental number of degrees, starting from zero at whatever position the lever is in, at the powering-up of the sensor. This is then converted to an angle of crank rotation, starting from the top-dead-position (TDP), when the data is changed into a spreadsheet format.

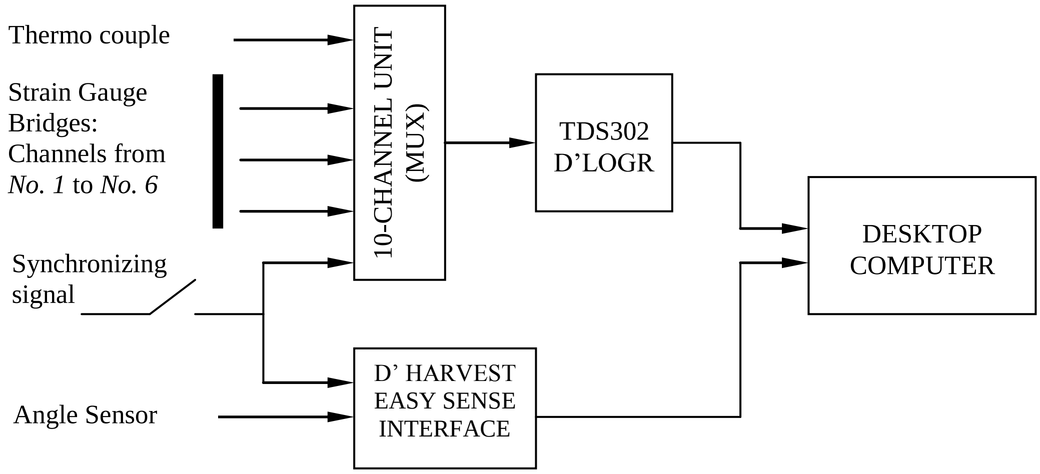


Fig. 7 Block diagram of the Instrument System for the forces and moments measurements.

V. MEASUREMENT RESULTS

The figures below present the experimental result obtained for 18 trials in smooth curves as follows: Fig. 8 illustrates the variations of the compression forces acting on the face of the piston owing to the seeds being crashed in the cage; Fig. 9 displays the variable bending forces acting on the lever corresponding to the forces applied on the handle by the operator; Fig. 10 indicates the variation of tension forces in the connecting rods, and Fig. 11 describes the variable bending moments on the connecting rods as a result of the friction torques induced in the sliding bearings of the rods. All signals are recorded continuously from the six channels in a discrete form and after that they were transformed to produce smooth curves.

Because of different velocities of rotation of the handle by the operator during each trial the results obtained scatter significantly. If the lever of the machine would have been rotated with a constant angular velocity then all the graphs would be ultimately located very close to each other, even they may overlap, provided that the properties of crashed seeds are the same during the experiments.

Unfortunately this is not the case as the operator is not capable of applying a constant force on the handle and maintaining the constant velocity. This is because at every 30^o-55^o position interval of the lever he has to change the way his hands act to the handle keeping the lever turning. That is why in all the graphs within the above range of rotation, the recorded forces and moments rapidly change following the variation of the force acting on the handle. At this point picks are recorded for forces and moments following the changes of forces on the handle provided by the operator.

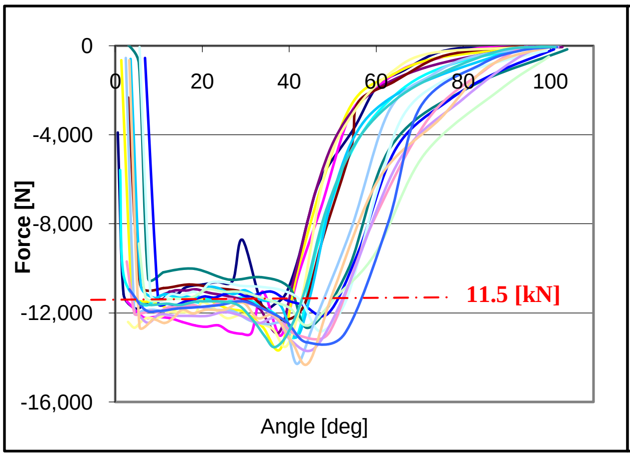


Fig. 8 Variable compressive forces on the piston

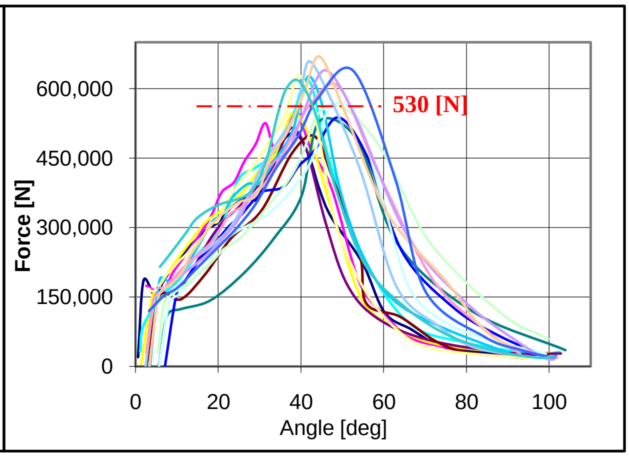


Fig. 9 Variation of forces on the handle

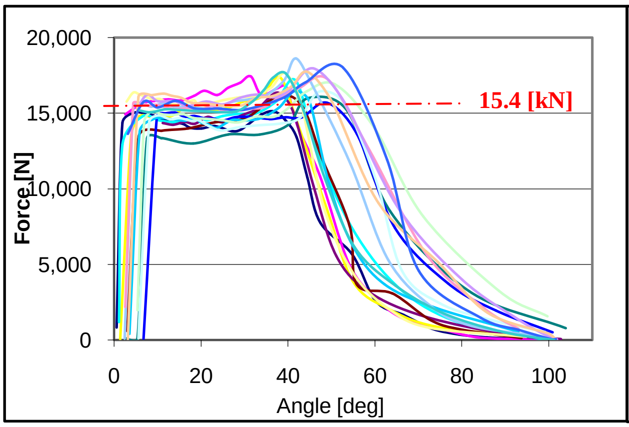


Fig. 10 Tension forces on the connecting rods

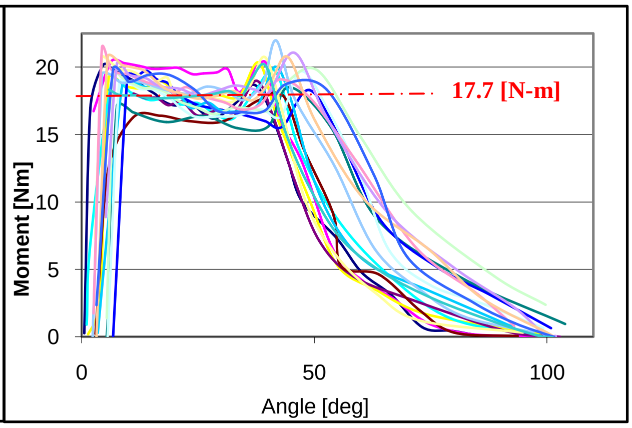


Fig. 11 Bending moments on the connecting rods

In addition to these problems the synchronization of the lever position and the recorded forces and moments seems to differ. The latter and the diverse variation of forces and the scatter of graphs create serious difficulties when the resultant graphs of the above relationships have to be obtained. These are required for the next steps of the analysis which may include determination of the energy balance, energy losses, and estimating the mechanical efficiency of the machine.

For example, if Fig. 8 is considered all the recorded graphs characterizing the variable compressive force acting on the piston during the crushing process of the seeds for the 18 trials of the machine performance. Practically it is essential to have one typical or say a resultant graph averaging all recorded graphs in order to calculate the useful work done by the piston per cycle of crashing the seeds. The latter is equivalent to the area under this graph and is important part in the analysis for the useful work done by the machine per piston stroke.

In fact the graphs obtain in all of the above figures represent forces and bending moments corresponding to the positions of the lever of the machine. They provide significant information of how the machine members interact, what amount of energy is utilized for crushing the seeds (useful work) and the amount of energy lost due to friction in the bearings and in the piston-cylinder pair.

Next, the area under the resultant graph representing forces acting on the handle (Fig. 9) ultimately gives the work done by the operator to overcome all internal forces and stands for the energy input in the machine. This energy is spent for a useful work done by the piston and the rest is exhausted in the form of energy losses due to friction in the bearings and the friction between the piston (ram) and cylinder pair. The above information is essential for calculating the energy balance within the slider crank mechanism, including the energy losses and ultimately in estimating the energy efficiency of the ram press.

The variation of the tension force in the connecting rods (Fig.10) and the corresponding bending moment induced (Fig. 11) allow to assume that the friction torques in the bearings are equal to the bending moments. Therefore trough the resultant friction torque and friction force equations one can estimate the value of the actual coefficient of kinetic friction in each bearing of the connecting rods. Based on these data the energy lost due to friction can also be estimated and the energy balance could be accurately calculated to help assessing how much of the input energy is spent for crushing the seeds and what portion of it is lost to overcome friction in the bearings and in the piston cylinder pair [7]. All these multiple curves in the respective figures should be replaced by one resultant curve for each figure in order to calculate the area confined under the curve and estimate the corresponding work done. The conversion of the multiple graphs into a single resultant graph for each figure is a complicated process requiring a non-standard statistical approach and is beyond the objective of this paper. This will be done during the final step of the analysis in the next study.

Now by analyzing the graphs in the above figures the average maximum values of the corresponding forces and bending moments (friction torques) are found to be as follows: From Fig. 8 the maximum average value of the compression force acting on the face of the piston is estimated to be 11.5 kN; From Fig. 9 the maximum average force applied by the operator on the handle is 530 N corresponding to the lever position angle of about 45^o; From Fig. 10 the maximum average value of the tension force in the connecting rods is found to be 15.4 kN, and from Fig. 11, the maximum average value of bending moment acting on the connecting rods as a result of frictional torques generated in the end bearings is estimated to be 17.6 N-m.

Now by using the maximum average value of the bending moment the coefficient of kinetic friction in each of the sliding bearings of the connected rods is calculated. It is evident that the maximum average bending moment acting on them is equal to the friction torque in the bearings as stated above. Thus the average value for the coefficient of kinetic friction is calculated from (1) as follows:

$$\mu = \frac{F_f}{N_{pin}} = \frac{T}{r_{pin} \times F_{pin}} = \frac{17.7}{0.016 \times 15400}$$

$$= 0.0718, \qquad (1)$$

where:

$F_f = \mu.N_{pin}$, [N] - is the resultant friction force in each bearing,

$T = F_f.r_{pin} = \mu.r_{pin}.N_{pin}$ [N-m] is the friction torque produced by the resultant friction force F_f acting in the bearing,

$BM = T = 17.7$ [N-m] - is the maximum bending moment (friction torque) acted upon the connecting rods (Fig. 11),

N_{pin}=F_{pin}=15400 [N] – is the tension force in the connecting rods as found from Fig. 11, signifying the normal reaction acting on the bearing, and

r_{pin} = 0.016 [m] - is the radius of the journal (pin) of the sliding bearings.

The value of actual coefficient of kinetic friction obtained above appears to closely match the typical value listed as μ_k = 0.01-0.05 (0.09) for the case of “steel on steel” with lubrication [6]. According to these authors a variation of 25% to 100% or more from this value could be expected in actual applications, depending upon the prevailing conditions of surface cleanliness, surface finish, contact pressure, lubrication, and sliding velocity. In this study the calculated value of the coefficient of kinetic friction differs by 20.2% below the listed maximum value shown above in the parentheses.

Consequently the result suggests that the recorded data concerning the bending moment and the tension forces in connecting rods are reasonable and provide reliable information for the purpose of this investigation. Based on the above findings it could be assumed also that the results for the forces on the handle and on the piston are consistent. Therefore they can be applied for the subsequent analysis regarding the energy balance in the slider crank mechanism of the ram press machine BP30.

VI. CONCLUSIONS

This paper deals with the experimental setup for ram press machine BP30 and discusses the arrangement of the strain gauges and the equipment used for measuring forces and moments acting on the machine elements. The paper also presents the experimental results obtained for 18 trials concerning the forces acting on the handle and the piston (ram) along with the bending moments created on connecting rods. The results are presented in graphs, which allow conducting further analysis and calculations of the energy balance, energy losses and energy utilization in the ram press machine under operating conditions similar to those done in [4, 7].

Based on a preliminary analysis of the graphs the maximum average values of the corresponding forces and moments are determined. By using these data the maximum value of the coefficient of kinetic friction is found to be $\mu_{k,\ max} \approx 0.072$. It is also revealed that the result agrees with the tabulated values of the coefficient of kinetic friction applicable to lubricated steel on steel sliding surfaces [6]. Further it is found that the value of μ_k deviates by 20.2%, which is acceptable for the conditions at which the measurements were conducted. Even larger variation of the actual values of the kinetic coefficient of friction may be anticipated due to the uncertainties influencing the contacting surfaces. Among the factors affecting the value of the coefficient of kinetic friction are the surface finish, contact pressure, degree of lubrication and surface cleanliness, all contributing appreciably and more than 100% higher values may be feasible [6].

Special statistical analysis is to be done as the next stage of this investigation in order to obtain the corresponding resultant graphs of all those presented and discussed in this paper. The new single graphs would provide prospects for estimating the input and the output (useful) energy as well as to find out how the input energy is utilized by the machine. The latter might be accomplished by estimating the work done by the operator (input energy), the useful work done by the piston and the energy losses owing to the friction in each of the interacting elements of the machine that is in the bearings and sliding pairs. Then, a full energy balance may be conducted similar to this done in [4, 7] but with much higher degree of accuracy, because of the use of the sophisticated measuring equipment. Since similar results are already available for the design of BP42 ram press machine reported in [4] a comparison analysis may be carried out as per [8] and evaluate which design is better in terms of the minimum force required on the handle, the machine efficiency and friction losses. Also the parameters contributing positively to better mechanical efficiency and appropriate usage of energy would be eventually identified and used in the future to improve the ram press design.

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