# Control Measurement of Industrial Machinery

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**Key words**: control measurement, setting measurement, press machine.

## SUMMARY

In this study special control and setting measurements are presented from the speciality of mechanics. Since more than two decades the authors have been taking part in the measurement of heavy-duty press machines with that number of different aluminium products are manufactured. The purpose of measurements is to determine the spatial coaxial deviations between the different machinery of press machine and to detect the reasons of other anomalies in the imperfect operation of press machines. The coaxiality of axes of machinery is only one of the prerequisite of the perfect operation of press machine within couple of tenth millimetre of tolerance. There are needs for control measurements not only under repairs but in such cases when something breakdown occurs as well. The main problem from geodetic point of view is the short time to achieve the control measurements. Furthermore drawbacks are the different obstacles in sight that disturb the performance of observations as well. These were the main reasons why we had to find out such measuring techniques that are simple, follow the circumstances and can be performed rapidly.

In our study we discuss the technology of setting and control measurements, the applied data processing methods and some difficulties that we have to face through the measurements pointing out the significant role of geodesy during the solution of this very special task.

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## 1. INTRODUCTION

The formation of engineering geodesy and its application have proved over the past decades that geodetic instruments and measuring technologies may be used for not only geodetic tasks. The geodesy has verified that it is suitable to perform high precision-required measurements in several fields of engineering specialities. In the 1980s, see Werner (1987), the experts were in dispute about that whether the mechanics would be a newer application area of the geodesy or not. At the time, the mechanical metrology had had peculiar measuring instruments and special measurements were performed by their use. However, it can be occurred that mechanical instruments and methods cannot be applied under certain circumstances. This is the point when the geodesy enters into the process getting bigger and bigger role during the solution of a particular task.

The College of Geoinformatics has been undertaking different works permanently in ALCOA-KÖFÉM since 1982, where we work on the metrological solution of mechanical problems. The ALCOA-KÖFÉM is one of the biggest half-ready aluminium manufacturers in Central Europe, where aluminium moulds, rolled plates, simple and complex aluminium shapes are manufactured. Number of mechanical machinery is used for different product technologies that need regular maintenance and renovation involving control and setting measurements, too. Most of tasks are related to control and setting measurements of machinery units of press machines. There are six different generations of press machines in the factory, and of course, more or less, they deviate from each other.

Basically, the press machines consist of three main units that are moved or fixed. The product process is rigorously standardized in ALCOA KÖFÉM and the products have to satisfy these strict requirements. One prerequisite of the perfect operation and production is that the above written units have to satisfy certain coaxial conditions both horizontally and vertically. In our study, we present those measuring technologies that have been developed for this purpose. Either of method is based on the use of optical instruments, namely Zeiss Theo 010 A theodolite and Zeiss NI 002 A precision level. We also point out how we can exploit the possibility of forced centring measuring technology interchangeably by these instruments. However, this technology has the well-known drawback, namely, the three dimensional determination of position cannot be carried out simultaneously. Thus we worked out another technology that is based on the use of total station. In this case the data process requires more complex calculations that are carried out on laptop. Despite the seeming simplicity of the control and setting measurements, there are furthermore major factors that cause limitation on the accuracy. One is the distance between the station and target points, the other is the range of the total measuring and setting time, which can take many hours, but sometimes a couple of days.

## 2. THE CONTROL AND SETTING MEASUREMENTS

The control and setting measurements are based those reference measurements that were performed through the building of press machines many years ago.

When the press machine was under construction it might have been seen and measured through. Number of control points and axis points were marked during the construction and settings out, but only the so-called axis points remained that can be seen in Fig. 1. Later the elements of press machine caused obstacles during the observations therefore only the two remaining axis points before the front plate can be used for setting measurements. The marked points are sunk into the floor being in a steel box and saved by a rustproof spiral cap. The centre of point is a small hole with a diameter of 1 mm.

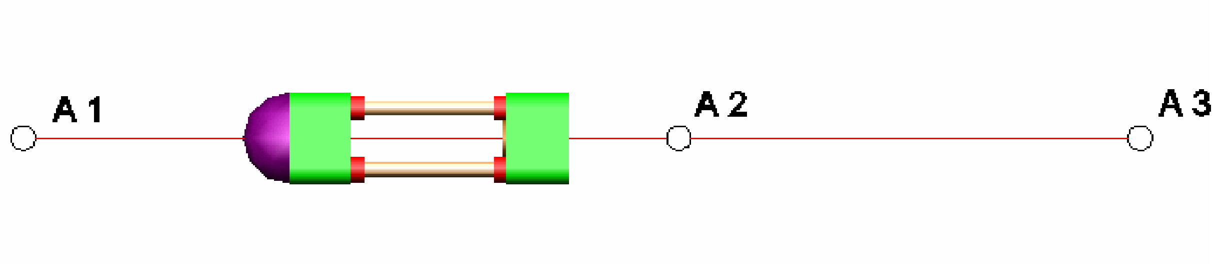


**Fig. 1**

As we have written in the previous chapter, the task is to set the axes of the three main machinery elements into coaxiality (Fig.2). These are the ram, the container and the centre of die exchange cassette. The measuring process contains two main steps from the point of view of measurements to be performed. First, the axis of ram has to be determined in an arbitrary height reference system at its starting position. This starting position is same as the position of main cylinder. For this reason one height reference point is marked close to the press machine. Usually this measurement can be performed in one or two stations because of the bigger height difference and other obstacles in sight. NI 002A precise level instrument is used for the measurement because we often target through very narrow gaps therefore digital level cannot be employed. The observation is repeated two times. If the difference between two values does not exceed 0.1 mm then the mean value is accepted finally. We have to note that the height reference points are often demolished through the production because of the waste material, repairs and other reasons. For this reason we are obliged to use temporal height reference point through the setting and control measurements.

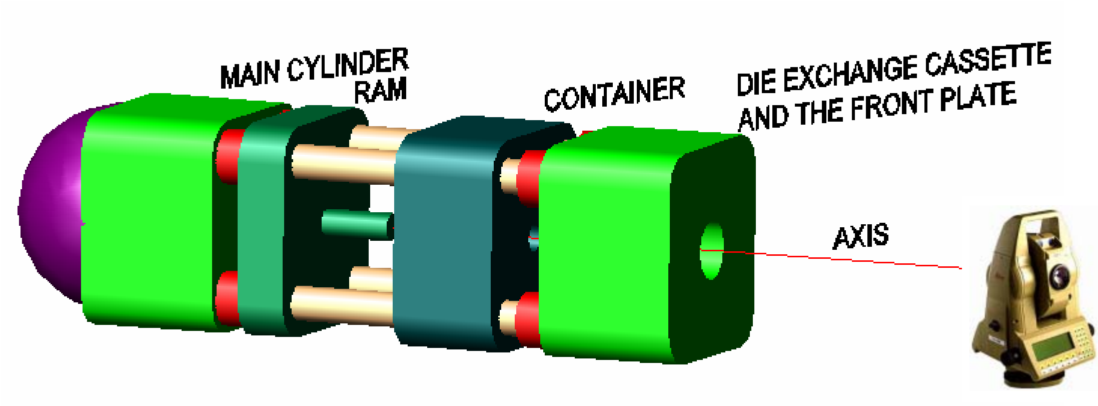


**Fig. 2**

After we have determined the height of axis of ram we set the theodolite from the front of press machine within 7…15 m. Since we cannot place rod onto the points of machinery, the theodolite has to be set so that the instrument height should vertically coincide with the axis of press machine within 5 mm. The so-called foresight reading on the level is given only by the reading on the micrometer of which range is 10 mm. On the other hand, the so-called container can be measured only if a special tube is placed in it, which we can see through. If the instrument height deviates from the axis more than 5 mm, then we cannot see through the tube. The instrument height is generally between 800 and 900 mm therefore we use a special small tripod that was created for this purpose.

In the case of die exchange cassette and ram we target a millimetre scale but we cannot use these scales to the measurement of container because it sways while it moves forward approaching to the die exchange cassette. Thus the container has to be measured at its front and back. The mentioned scales are made of metal and opaque so they do not allow seeing through the tube. For this reason a crosshair is measured in the case of container that is mounted centrally at the front and back on the above mentioned tube. The diameter of the hole on the tube that we have to see through is about 20 mm.

Because of the peculiarity of press operation and its structure the setting measurements cannot be performed simultaneously for all machinery. First we measure the die exchange cassette, afterwards the ram and then the container comes next. Finally we perform a control measurement of die exchange cassette again, because it can displace during the long time of total setting. Since the mass of the different machinery can reach lots of tons therefore the vertical and horizontal settings have effect on each other. Couple of tenth millimetre setting horizontally can result several tenth millimetre displacements vertically and vice versa. Usually three, but sometimes four different horizontal positions are necessary to measure the ram and container along their motions.

The lateral deviations are measured by reading on the above written scales when we use optical theodolite. In the case of container, this deviation is estimated based on the diameter of crosshair that is 0.2 mm.

The vertical deviation can be calculated using the following simple formula

$$d_V = \left( \frac{B_1 + B_2}{2} - \frac{M_1 + M_2}{2} \right) - \Delta H \qquad (1)$$

Where $B_1$ and $B_2$ are the backsight readings on the rod, $M_1$ and $M_2$ denote the readings on the micrometer of level in two-compensator states as foresight readings, and $\Delta H$ is the height of axis to be set. Because of the inequality of the distances between the backsight and foresight, the one of the greatest advantages of NI 002A level can be exploited measuring in two compensator states. The mean value determines the so-called quasi absolute horizon and that is why this instrument is so suitable in such an application.

The horizontal and vertical measurements are performed in succession depending on the success of horizontal or vertical settings performed by mechanics. For example the ram is measured horizontally at three different positions when it moves forward. Then the centred forcing replacement of theodolite and level comes next and we begin the vertical measurement while the press moves forward again. Afterwards the foremen set the machinery and we begin the observations again.

There were two main reasons why theodolite and level were used during the years. The first one was that the settings were performed with pre-heated press machine earlier. The temperature was often unbearable close to the press machine. Despite these difficulties, this technology was used in order the circumstances get closer those ones, which occur through the product process. This often resulted that the 0.1 mm accuracy of settings were not fulfilled. We often obtained 0.5 mm differences between two repeated readings on the micrometer. We had to face similar situation in the case of horizontal observations, too.

It was also desirable to shorten the observation and setting time performing the horizontal and vertical observations simultaneously. When this idea appeared a couple of years ago then our problem was that we did not have total station with laser distance-meter. That is why we could not measure distances directly to the elements of press machine. Secondly, such a total station might be considered with that the expected accuracy of settings can be kept without repeated observations. Since the Leica TC 1800 was the most accurate total station that we had at that time, and also nowadays, therefore we chose this instrument. The standard deviation of horizontal and vertical angle measurements are also 1” that corresponds to 0.1 mm with respect to a distance of 15 metres. We achieved experimental measurements in the measuring hall at our college in order to compare the result of two different technologies. To simulate the circumstance of the setting measurements as well as it is possible we used same tube as it is used during the settings. As the result of these experimental measurements, the vertical and horizontal deviations gave same results within 0.1 mm, so we did not have any doubts about we were going to use total station for furthermore settings and control measurements assuming the press machine would not be heated.

When total station is used for settings then the instrument height cannot be measured directly. It has to be derived from zenith angle and distance measurements. In this case also a rod is placed on the height reference point. The distance between the station point and the rod is very short. It never exceeds five metres. Targeting an arbitrary graduation $L_R$ of the rod in the approximate height of horizontal axis we measure the horizontal distance $D_R$ onto a tape that is mounted on the rod and read the zenith angle $z_R$ belonging to graduation $L_R$. Then the instrument height is

$$H_I = L_R - D_R \cdot \tan(90 - z_R) \tag{2}$$

In order to control the goodness of the determination of instrument height we measure the rod at two different graduations. In the property of instrument height the height of a point P on the machinery can be calculated as the follows

$$H_P = H_I + D_P \cdot \tan(90 - z_P) \tag{3}$$

This value has to be compared with the initial height of axis of ram. The lateral deviations are determined also trigonometrically. The station point and the other endpoint of the axis determine the reference direction. The lateral deviation is

$$d_{Hz} = D_P \cdot \tan(L_P - L_{A3}) \tag{4}$$

Where $L_P$ and $L_{A3}$ are the appropriate directions with respect to a machinery point P and the endpoint $A_3$ of axis (Fig. 1), above that a tripod is set with a target temporally.

The distance measurements are performed to reflector tapes mounted on the die exchange cassette and ram. In the case of container we can measure distance only to its front. If the back crosshair is measured then the length of container is taken into consideration to the calculation of horizontal and vertical deviations.

Since the settings require more complex calculations when total station is used, therefore we wrote a simple program to accomplish this task. The input data beyond some additional information are the height of axis to be set, the reading of the graduation on the rod, the zenith angle and the horizontal distance belonging to this graduation. In the property of these data, the program computes the instrument height and then the measurements of machinery's points come next. We have to note that distance is measured to one point of press machinery usually once, at the beginning of the first control. Computer and its personnel control the motion of ram and container. Despite the huge mass of machinery, they can be stopped at approximately same position, but maximum within several centimetres. Since the horizontal and vertical deviations are not sensitive to the changes of distance therefore it is sufficient to know their value within 10 cm.

In contrast to the successive use of optical theodolite and level, we can reduce the clear measuring time more than fifty per cent with total station. Besides, we can avoid the forced centring replacement of theodolite and level that can also take time. The results of calculations are saved in a file that can be viewed and handed over to mechanics for appropriate documentation immediately.

## 3. THE ACCURACY OF CONTROL AND SETTING MEASUREMENTS

In this chapter we present the estimation of standard deviation of horizontal and vertical settings when total station is used. Taking equation (1), (2) and (3) into consideration the vertical deviation can be calculated as the follows

$$d_V = H_P - \Delta H = L_R - D_R \cdot \tan(90 - z_R) + D_P \cdot \tan(90 - z_P) - \Delta H \tag{5}$$

Since the distance $D_R$ between the station point and the rod is very short therefore the effect of zenith angle $z_R$ on the vertical deviation $d_V$ is practically zero. Thus it is sufficient to form the partial derivatives with respect to $z_P$ and $\Delta H$. Applying the law of error propagation we obtain that

$$\sigma_{dV}^2 = \left(\frac{\partial d_V}{\partial z_P}\right)^2 \frac{\sigma_{ZP}^2}{\rho^2} + \left(\frac{\partial d_V}{\partial \Delta H}\right)^2 \sigma_{\Delta H}^2 \tag{6}$$

Since the zenith angle is close to the horizon therefore the partial derivative of first term in equation (6) can be simplified. Thus the two terms of equation (6) can be written as the follows

$$\sigma_{dV}^2 = \left(\frac{D_P}{\rho}\right)^2 \sigma_{ZP}^2 + \sigma_{\Delta H}^2 \tag{7}$$

As we have mentioned, the height difference $\Delta H$ is measured two times and the maximum tolerance of this observation is 0.1 mm, that is, the estimated maximum of standard deviation of mean value is 0.05 mm. Considering, that the distance $D_P$ is maximum 15 metres and the standard deviation of vertical angle measurement is 1" the value of equation (7) is the following

$$\sigma_{dV} = \sqrt{\left(\frac{15000\text{mm}}{206265}\right)^2 (1'')^2 + (0{,}05\text{mm})^2} = 0{,}08\text{mm} \approx 0{,}1\text{mm} \tag{8}$$

This value was confirmed by the experimental measurements as well about that we have written above, when we compared the height differences using optical instruments and total station.
Applying also the law of error propagation the standard deviation of horizontal setting can be calculated approximately as the follows

$$\sigma_{dHz} = \sqrt{2 \cdot \left(\frac{D_P}{\rho}\right)^2 \sigma_{Hz}^2} \tag{9}$$

Where $\sigma_{Hz}$ denotes the accuracy of horizontal direction measurement. In equation (9) we have taken the standard deviation of the measurement to the endpoint of axis into account, and the small values of horizontal deviations. Assuming that the standard deviation of direction measurement is 1” and the maximum distance $D_P$ is 15 metres, the estimated standard deviation of horizontal setting is 0.1 mm.

## 4. FURTHERMORE CONTROL MEASUREMENTS IN THE CASE OF IMPERFECT OPERATION OF PRESS MACHINE

In this chapter we give a short overview on furthermore control measurements. There is need to perform such measurements because sometimes the settings cannot be achieved properly as a result of the imperfect operation of other machinery. These can be occurred when certain geometrical conditions are not fulfilled. Either of problems is that the container collides with the die exchange cassette before that the so-called pressure ring is. The pressure ring is worn by the container and as the result of this, the container lurches when it gets the pressure ring. Our task is to determine the measure of deformations of pressure ring. The second main problem is that the so-called tie rod nuts (Anker-screws) are not parallel to each other spatially.

In the first case we set out a straight line parallel to the so-called cross lattices. The cross lattices are also mounted on the front plate in that the die exchange cassette is placed. The cross lattices can be found close to the ring, but the container does not wear them during its motion (Fig. 3). Next we measure usually eight points along the perimeter of the pressure ring reading on a calliper that is mounted on it by a magnet.

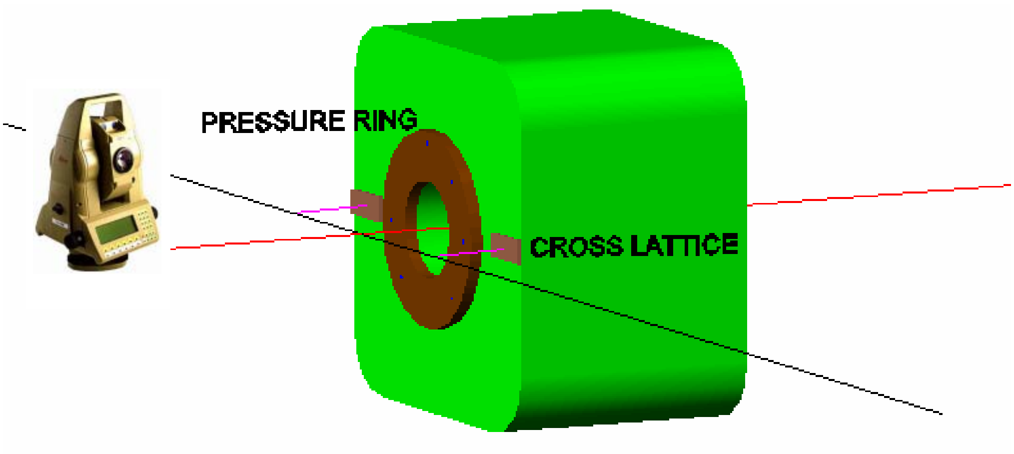


**Fig. 3**

The spatial alignment of pressure ring can be modelled based on the readings in a spatial coordinate system. Subsequently we compute a plane by adjustment (Csepregi Sz., 1998) to determine the tilt angle and the deformations of pressure ring. These deformation values serve as a basis to grind the pressure ring to adjust its deformed surface.

To the measurement of tie rod nuts we establish a micro-network. Where obstacles are in sight we have to measure furthermore auxiliary quantities using calliper. The network is adjusted as a free network and the coordinates are transformed into such a coordinate system of which either of axes is parallel to the axis of press.

The most important thing from the viewpoint of operation of press is to know the horizontal distances D between the vertical surfaces of tie rod nuts (Fig. 4). These quantities can be determined with high accuracy applying this method. Fig. 4 shows such a micro-network, that had relative accuracy of 1/70000. The standard deviation of coordinates in the direction of the axis of press was 0.1 mm in the case of six screws, and 0.2 mm at the remaining two screws.

This means that the horizontal distances between tie rod nuts in the parallel direction of the axis of press machine can be characterized with 0.2 mm in accuracy. Other direct measurements cannot guarantee such accuracy. Afterwards the mechanics make decision on the necessary settings of tie rod nuts based on the calculated distances and their differences.

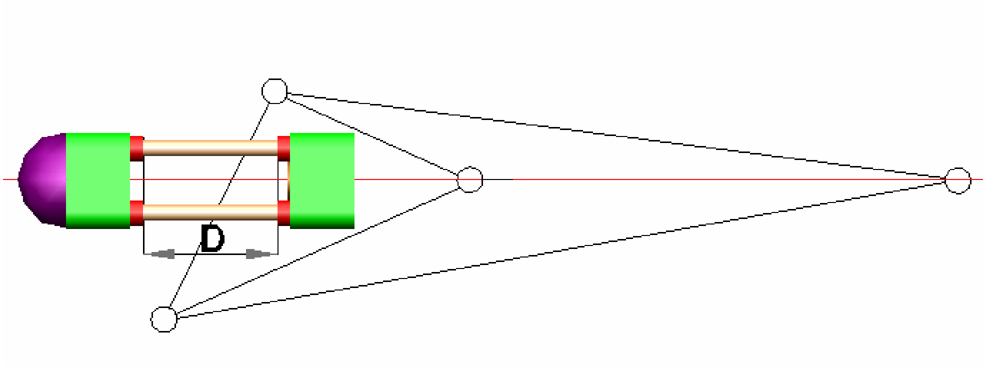


**Fig. 4**

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## BIOGRAPHICAL NOTES

**Mihály Ágfalvi** currently works as a Professor at the Department of Geodesy at the College of Geoinformatics, University of West Hungary (NyME GEO, Szekesfehervar). He graduated as a land surveyor engineer at the Technical University of Budapest in 1967. He worked at the Company of Surveying in Budapest from 1967 until 1970. In 1970 he was appointed as assistant at the Department of Geodesy of the College of Surveying and Land management in Székesfehérvár. He obtained his Dr.techn. academic title in 1979 at the Technical University of Budapest. He took actively part in the work of Hungarian National Comitee (HNC) of FIG and was the president of HNC from 1998 to 2002. He is also the member of the executive committtee of Hungarian Association of Geodesy Cartography and Remote Sensing and the presidency of Hungarian Chamber of Engineers. His teaching and research work are focused on Engineer Geodesy.

**Róbert Gyenes** has been working as an assistant at the College of Geoinformatics since 1997. He graduated as a land surveyor engineer (BSc) at this college in 1996. After his studies, he worked one year at a cadastral surveying firm. At the present, he is studying Geomatics at the University of Applied Sciences, Karlsruhe. His research field is the different data processing method of geodetic measurements, adjustment computations and he took part in some research projects of recent vertical movements of Hungary.

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