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MICRO-NETWORK CREATION IN INDUSTRIAL SURVEYING

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Abstract. Industrial surveying is special field of work within engineering surveying. In this article we have documented some procedures and principles which are very special in industrial surveying.
A micro-network consists of net points which are set as a base for all surveying in the industry. These points create coordinate system for all measured parts of the machine. For realization of micro-network are used well known geodetic methods such as triangulation, trilateration, levelling or trigonometric high. As horizontal and vertical controls do not exist in a factory hall, a surveyor has to find some different method to start working.

Keywords: micro-network, industrial surveying, mechanical engineering.

1. Introduction

Geodetic measurement of machine parts and metal constructions in the industry is a special field of engineering surveying. According to ČSN 730401 (1990) is industrial surveying used anywhere is not possible to use traditional mechanical tools for measurement, like dial micrometer, gap gauge etc. A surveyor uses for his work theodolites, levelling instruments, total stations or various types of laser equipment. Sophisticated laser instruments such as laser trucker and interferometer are not commonly used in factories. However, theodolites, levelling instruments and total stations are quite frequent. These instruments are more suitable for measurement of large and rugged industrial parts like crane trucks, rolling mills, large steel constructions, and etc. In mechanical terminology, geodetic measurement is referred to as "optical" measurement.

A surveyor co-operates with the production, verification of the construction and preparation of parts for transport, setting out of the parts for the construction assembly on site and verification of the assembled parts before operator acceptance. The necessity for optical measurement is very often used not only for new machines but more for machines which are just being produced (Asociace… 2006).

The need for mechanical inspection of machine is important not only from the "optical" measurement point of view but from the technical state also. On the basis of the inspection results it is possible to improve its efficiency. Using correct procedures and well-planned inspections, it is possible to prolong the lifetime of the machine and its parts.

2. General principles for micro-network creation

In industrial surveying we do not use horizontal control and vertical control because there are none in the factory halls. Surveyor then has to find different beginning for his work. It is necessary to create micro-network which is based on completely distinct from common rules.

Micro-network surveying points, which can be called net points, work as a geometrical base for optical measurement, setting-out for the assembly work, verification of measurement and rectification. Micro-network is defined in local coordinate system. The dimension of point-to-point distances is connected to the dimension of the measured machine or device. The micro-network, which is created inside a factory building, is completely independent of outer horizontal and vertical control. The main emphasis is placed on geometrical determination and continuity of the machine, not on the machine location in the factory building. The micro-network is connected not only to the measured object but in many cases provides the continuity of the industrial machine. Basic micro-network shape is usually right-angled.

Net points create the main axis and the transversal axis. The main axis X goes in the centre of the machine and the transversal axis Y establishes the width of the machine, see example in Fig. 1. Both axes are created by at least two points. Then there are more points set which perform parallel axes. The number and densification of

these points is not specified by anyone because it depends on the length and segmentation of the measured machine. At least three micro-network points has to be created.

The actual shape and location of the basic net points and additional net points (densificated points) can be seen in Fig. 1. Shape of the micro-network which is shown is just illustrative example connected to a special case. This is not a general micro-network shape.

3. The methods to create the micro-network

The methods to create the micro-network are triangulation, trilateration, levelling or trigonometric high. These methods are well known but surveyor needs horizontal and vertical control as base for the measurement. There are no points in the factory halls. Thus, a surveyor has to find a different method to start working.

The following situations can occur:

– Micro-network creation according to the project- the net points are done by the project, set-out and density established according to measurement needs.
– Micro-network creation based on existing net points- utilization of the existing net points and density established according to measurement requirements.
– Completely new micro-network- creation of a micro-network for measurement needs.

3.1. Micro-network creation according to the project

In this case a completely new machine is assembled and all assembly is carried out according to the project.

The whole process of the micro-network creation begins with the building of the new factory hall or during the construction work for the installation of the new machine part. The real dimension of every surveying point is established by the project – horizontal coordinates X, Y. All the dimensions which are written in the project are in millimetres. Every coordinate of the net point is connected to the Zero point- the beginning of the local coordinate system. At this point X and Y coordinates are equal to 0,0 mm.

Places for the net points are built into the floor- the metal plates (approximately 100×100 mm) are roughly set in position according to the project. An accurate mark of the net point is done by the surveyor who will carry out the rest of the optical measurement work. An accurate mark is created on the metal plate like hole or dig line (see Fig. 2). These net points are used for all of the

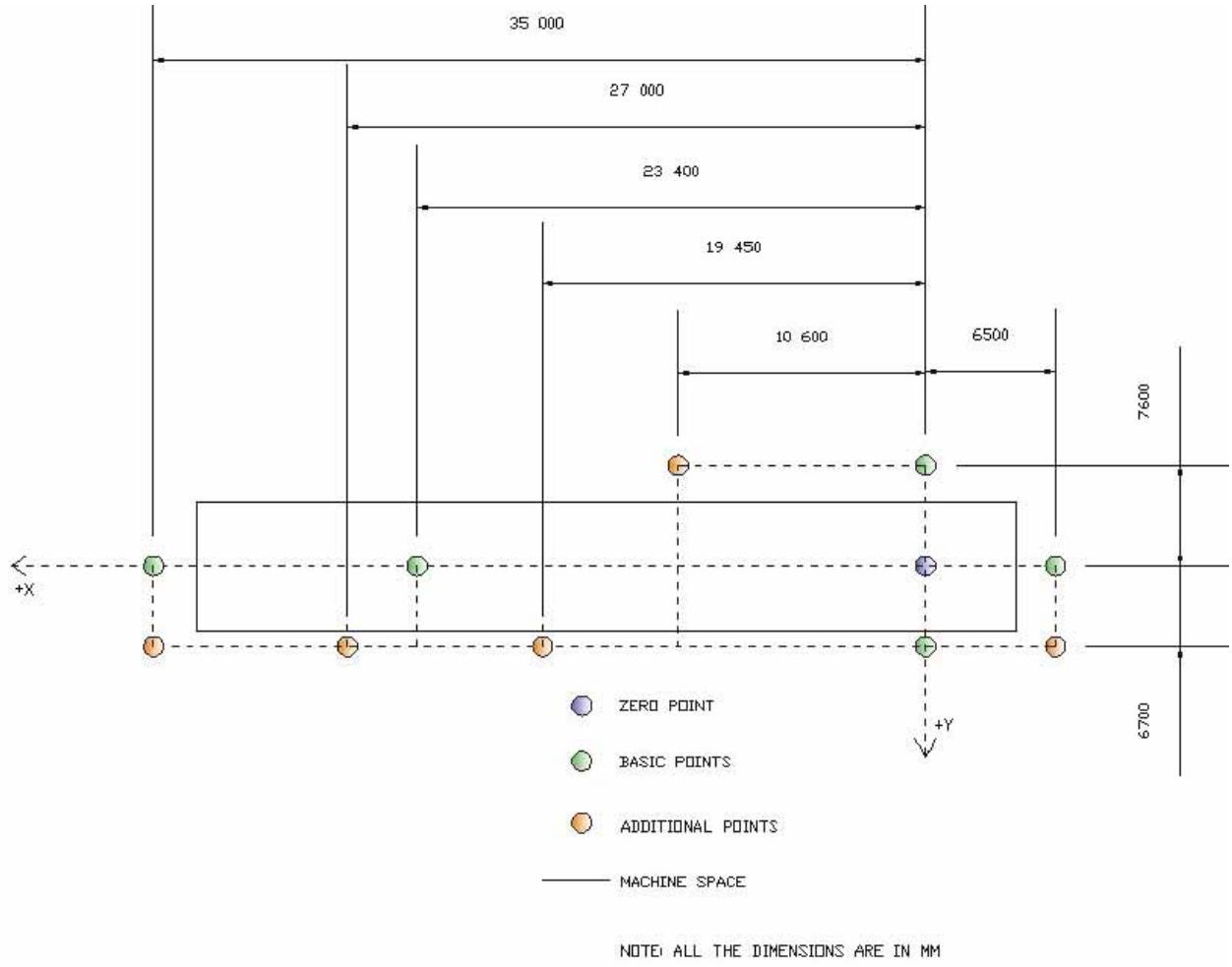

Fig. 1. Scheme of the micro-network points with dimensions

setting-out due to forced centering equipment. The machine is assembled and it can occur that some net points are not visible any more. This can reduce the number of net points which are used for the temporary station and the carrying out of measurement becomes complicated. That is why we have to create additional net points that are temporarily set on the walls or parts of the hall construction.

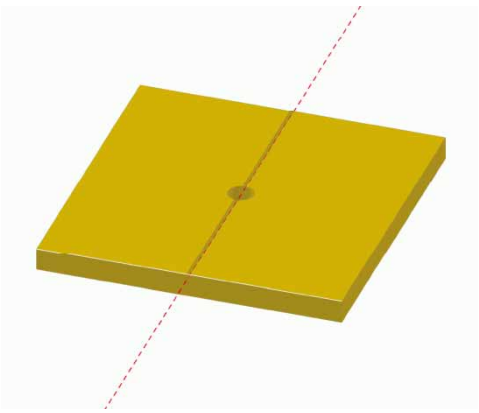

Fig. 2. Scheme of the permanent monumentation

3.2. Micro-network creation based on the existing net points

In this case the machine is assembled and the surveyor just comes and verifies the positions and continuity of the machine parts. They can use existing net points which substitute the central machine axis or width machine axis. These points can be used for the orientation of the Total Station- chapter 3.1. The location of these points is usually on the floor of the hall so the surveyor can have problems using them after every position change of the Total Station.

All services and verifications are done when the machine is stopped. This means that many workers are required with a lot of equipment and material to transfer. That is why the surveyor uses the points on the floor only for the first orientation and then creates temporary points on the walls or construction of the hall. These temporarily placed surveying points consists of a magnetic base and surveying prism. Sometimes it is possible to fix the surveying prism on the wall as a permanent mount. The surveyor has to identify the coordinates of these points for other orientation of the Total Station and optical measurement.

3.3. Completely new micro-network

The last method used to create the micro-network is the situation when there are no net points as they could have been destroyed or inaccessible for the optical measurement. This can happen when the machine is older and nobody has any recollection of assembling it on site.

The main problem is to set-up the machine axis which is the base for the rest of the optical measurement. This important consideration can influence in a negative or a positive way the total measurement and evaluation. The surveyor who does not have any experience with this kind of measurement cannot solve this situation. It is necessary to know the machine- its construction and how it operates. That is why they have to communicate with the mechanical engineer or machine staff who know the machine. After that the surveyor can decide which part of the machine can represent the machine axis. The main orientation of the Total Station is based on that machine part and after that the surveyor can create the temporary net points on the walls or hall construction. The coordinates of these points are used for all the optical measurement of the machine. Sometimes it is necessary to create permanent net points for the next time a measurement is carried out.

It is important to know that this kind of optical measurement solves the geometry of the machine and the realignment of the crossed parts. Every measured part has to be parallel or perpendicular to the machine axis according to the machine construction. When the measured machine part is misaligned it is necessary to put it in the correct position. Some parts can weigh a few tons and the manipulation of it can be very difficult or impossible. In that case the reduction of the position can not be done and the machine engineer has to find another way to align the measured and connected parts.

For instance the rolling mill- the main function is forming of the material with the help of pressure between a couple of rolls- (see Fig. 3).

Fig. 3. Principle of the rolling mill

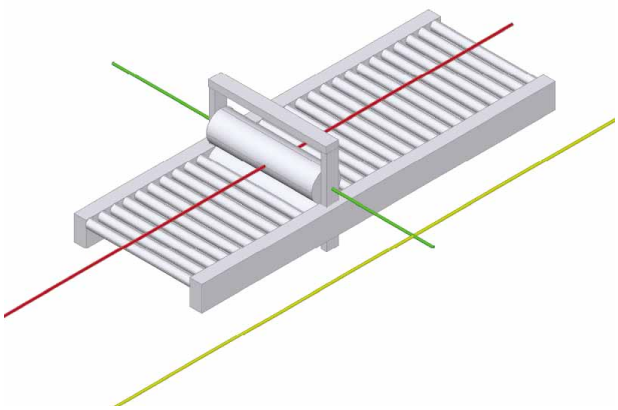

Fig. 4. Axes creation at the rolling mill

The entire unit of a rolling mill consists of many rolls which transfer material toward the working rolls (Fig. 4). The press is the biggest and the most important part of the machine. The axes of the rolls have to be parallel- the material has to be guided correctly to the press, then formed to the expected shape and then moved out. That is why the press is meant to be the base for the whole measurement. One of the working rolls performs the perpendicular axis (green line). To that axis is set the

main axis of the machine (red line). This line is not the best for measurement so it has to be moved parallelly out of the machine (yellow line). Then it is necessary to fix the created machine axis with the help of temporary net points.

4. Equipment and tools which can be used

The accuracy required in the mechanical industry is below one millimetre and so the surveyor has to use appropriate equipment and tools. Short distance between two pieces can be set by a slide calibre and the levelling of the machine part can be set by a sensitive inclinometer (0.1 mm/m or 0.01 mm/m).

The measured quantities surveyed are distance and angle. For industrial purposes these quantities have to be more precise than in land surveying. It was common in the past that there were columns in the factory buildings for forced centering. The distances were measured with a tape or using parallactic distance measurement method and the angles were measured with a one-second theodolite (Zeiss Theo 010, Wild T 2m, etc.). The forced centering then provided high precision of the created micro-network. These methods are archaic, time consuming and not possible to use in today's working conditions. At present the surveyor can use heavy tripods and Total Stations which can measure distances and angles at the same time.

The accuracy of industrial Total Stations is 0.3 mgon in angle measurement and 1 mm + 1 ppm in distance measurement. These Total Stations are made by Leica (TDA5005 and TS30) or by Trimble (S6, S8). The surveyor has to use appropriate tools like reflective tapes or reflectors. Passive reflection can not be used in industry under any circumstances.

Standard reflective prisms have a centering accuracy of 2 mm which is absolutely unsatisfactory for industrial measurement. In that case it is necessary to use special reflective prisms such as Leica GPH1P Professional with a aim accuracy 0.3 mm or a one-inch ball prism. The surveying points on the floor are created with the help of a special tool. The shorter the distance between the floor and the centre of the prism, the higher accuracy of the centering. That is why the prism is fixed to the special triangular base with levelling screws and two perpendicular spirit levels. The net point is then projected on the floor.

Example:

If the electronic distance meter precision is ±0.2 mm/100m, then on a distance of 40 m, there is a distance deviation of ±0.08 mm. Angle measurement accuracy is done by the Total Station producer. If the precision is α = 0.15 mgon then the angular deviation Op is set with the formula

$$Op = tg\,\alpha \cdot s. \tag{1}$$

When the distance is 40 m, the total angular deviation of the point is 0.09 mm. The total position deviation of the net point is 0.12 mm. Used formulas and symbols follows Czech standards (Terminologický... 2005–2011).

Thanks to mathematical and physical reductions and other functions, the process of optical measurement can be faster and the surveyor can get the values almost immediately. New Total Stations can use the method of the temporary station, transformations and the method of least squares to minimise deviations. These functions make the surveyor's work faster and easier and do not prolong the time spent on site.

5. Methods and accuracy of the micro-network measurement

The first step for micro-network creation or densification is going through the project documentation. The basic surveying points are set out but the surveyor can add some more to the project. During all assembling work, the rule is that visibility of at least two points has to be kept for orientation. This condition is very important because many of the projected points can be hidden below the construction of the machine.

Net points are usually set-out of the survey station with the polar method. The monumentating of the surveying points they are measured again and then should be micro-network equilibrated by the method of least squares. The surveying points have the coordinates which are used for the rest of the measurement. The positioning measurement of every machine part is done with the help of temporary station of the Total Station and the level deviations are set with the trigonometrical measurement of heights.

Standard position deviation of the surveying point is σ_{XYP} with the polar method according (Michalčák *et al.* 1985):

$$\sigma_{XYP}^2 = \sigma_{XY}^2 \cdot \left[1 + \frac{s}{d}\left(\frac{s}{d} - \cos\chi\right)\right] + \frac{1}{2}\left(\sigma_s^2 + \frac{\sigma_\chi^2}{\rho^2} \cdot s^2\right), \tag{2}$$

where: σ_{XY} – standard position deviation of a point in the micro-network (providing $\sigma_{X1} \cong \sigma_{X2} \cong \sigma_{Y1} \cong \sigma_{Y2} \cong \sigma_{XY}$); s – setting out of the distance; σ_s – standard deviation of the set-out distance; d – distance to the point of orientation; χ – set-out angle; σ_χ – standard deviation of the set-out angle; ρ – radian value in gon scale (63662 mgon).

Formulating from the 2 the standard position deviation of the surveying point in the micro-network then:

$$\sigma_{XY}^2 = \frac{d^2}{d^2 + s^2 - d \cdot s \cdot \cos\chi} \cdot \left(\sigma_{XYP}^2 - \frac{\sigma_s^2}{2} - \frac{\sigma_\chi^2 \cdot s^2}{2\rho^2}\right). \tag{3}$$

Inserting in the formula 3 values for Total Station Leica TDA5005 and measured values for the most unfavourable configuration: σ_s = 0.3 mm, σ_χ = 0.3 mgon, s = 50 m, χ = 200 gon, d = 60 m. These values were gained

from the calculation of this error. Then the standard position deviation of the surveying point when the necessary precision σ_{XYP} = 1.0 mm, is the standard position deviation of the point: σ_{XY} = 0.6 mm.

This value would be acceptable in the case that the measurement is done from the surveying points. Using the method of the temporary station, the final value of the station is set by the transformation of the measured orientations with the obtained deviations. These deviations should pass the criterion for σ_{XY}.

The whole measurement can be influenced by other factors:

- Errors of the measurement instrument are in industrial Total Stations very small and it is possible to reduce it with the help of the standard measurement procedures (measurement in both position of the instrument which is sometimes in the industry problem), using a three axial compensator on, calculation or instrument calibration.
- Errors in aiming and reading. These days the reading of the measured values is completely computerized and the aiming is computerized also. Function of the Automatic Target Recognition-ATR can find the target and aim automtically at the same place.
- Influence of the environment includes refraction which is insignificant to a distance of 50 m. One of the most influencial parts are heating sources which are very common in industrial surveying.
- Error of the instrument centering is eliminated thanks to the use of the temporary station. The error of the target centering is eliminated with the special tools for the fixing of the target.

6. Conclusion

This article introduces the procedures, mounting of net points and the precision of the micro-network creation in industrial surveying. The accuracy of these measurements and setting of the mechanical parts to the correct position is not specified by any law or legislation. The assembly work depends on the producer's tolerances and the user's requirements. But our experience is based on the procedures mentioned and the precision and accuracy of the measurement equipment used.

It is necessary to mention again that every machine and machine part is different and that micro-network creation is based on these differences. That is why the work has to be carried out with the co-operation of the machine engineer or machine staff and the experience of the surveyor. If these conditions are not fulfilled the surveyor can make the situation of the machine worse or even cause an accident.

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