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Power Engineering Survey Center

S R N Í

ENHANCING LIFECYCLES OF COMPONENTS IN POWER ENGINEERING MACHINES

Enhancing Lifecycles of Components in Power Engineering Machines

Dear ladies and gentlemen,

in closing of the 1st conference, I presented my paper dealing with "Deformations Development Monitoring in Foundation/Turbine-Generator Unit Systems" using geodetic survey measurement methods. The paper focused mainly on a method used for measuring deformations development in foundation/turbine-generator unit systems, its accuracy characteristics and method of the measured results assessment with respect to survey, engineering and construction aspects. Origins of deformations of foundation and turbine-generator unit rotation axis were only briefly outlined. Therefore, today I would like to add a few words about certain findings concerning deformation development monitoring in foundation/turbine-generator unit systems (F-TGU). At first, an introduction to the topic – some theory background.

Deformations of turbine-generator unit foundations.

Influences affecting deformation development in F-TGU systems and behavior of individual components are numerous and may be divided into two groups. These include:

1. Static strain of foundation occurring over time even when the unit is not in operation (irreversible deformations – in average the tolerances given in ČSN 73 1020 are exceeded in 6 years); and

2. changes caused by the turbine-generator unit operation (reversible deformations in most cases).

Static strain of foundation is caused by:

a) uneven foundation setting;

b) concrete creeping;

c) load impacts, etc.

Foundation deformations resulting from operational impacts are caused by:

d) temperature field changes of the F-TGU system during operation;

e) secondary load by piping, condensers, torque;

f) dynamic effects;

g) longitudinal or cross-section placement of turbine-generator unit in the machine room building;

h) influences in given location, such as geotechnical disruptions and other more or less substantial impacts, e.g. installation inaccuracies.

All these changes have impact on, inter-alia, the turbine-generator unit axis alignment.

Deformation of the turbine-generator unit rotation axis.

Shaft setup of the turbine-generator unit and rotor alignment to a so-called deflection curve is described in the paper presented at the 1st conference; mentioned description however is simplified.

Deformations of machine placement resulting in variations of set rotation axis to a deflection curve are not the only issue related to foundation deformations. In big machines where arrangement of the turbine-generator unit rotating parts and their stator parts is performed separately, varied foundation shifts translate into rotor-stator mutual position, known as centricity. When radial clearances are pushed to their limits, operational problems occur, often accompanied by vibrations, which eventually may lead even to the machine crash. In less serious scenarios the machine sealing wears out more intensively and its efficiency decreases. Excessive wear and tear leads to shorter lifecycle of parts or the machine as a whole.

Moreover, during repairs or long-term shutdowns the site load is alleviated causing retroactive time-related deformations, which complicate proper alignment of the turbine-generator unit.

As already mentioned in the paper at the 1st conference, foundation system deformation resulting from changed heights of bearings is not – apart from compromised centricity – the imminent cause of stronger vibrations. Changed rotation axis, however, induces changes of radial bearings load, which eventually may cause higher vibrations via various mechanisms. In addition, for rotors with fixed couplings, variations of rotation axis from calculated deflection curve lead to undesirable additional alternating bending stresses.

Permissible deformation of the rotation axis is therefore determined by allowable level of additional bending stress while maintaining high safety levels considering fatigue damages and allowable limited changes of bearings loads.

Top foundation slab (TFS) deformations in connection with the machine arrangement also must not lead to pushing the radial clearances inside the machine to their limits. If foundation deformations and operational deformations of the machine accumulate undesirably, serious collisions may occur.

Now, I would like to present certain findings about deformations development characteristics in different foundation types demonstrated on specific examples where deformation development in F-TGU systems was monitored.

Deformations of foundation and the turbine-generator unit rotation axis occurring over time due to static strain.

During power start-up of 1000 MW unit the turbine crashed and low-pressure (NT) rotor was seriously damaged. Installation of turbine-generator unit was accomplished in February 1996, followed by a series of tests. Upon these tests the rotors were aligned to prescribed values by changes of feet on flexible supports. This procedure actually did keep the rotation axis within permissible limits but it seriously disrupted centricity of individually placed low-pressure parts. These are placed on longitudinal beams, while bearing support stands are placed on cross beams. Causes of deformations for longitudinal and cross beams are of different origins. In the TFS, on the left-hand side, are installed pipes from separators. Despite good insulation and sufficient and loose dilatation joints the heat generated by these pipes during operation causes the longitudinal beams to deflect upwards.

Until its power start-up in September 2000 the turbine-generator unit was idle. During this period the static-type deformation of top foundation slab (TFS) had developed, as shown in fig. 1. This deformation subsequently increased due to operational conditions during power start-up. If we consider also the cross beams deflections, 2-4 mm by then, and longitudinal beams deflections, we obtain an image how the rotation axis was deformed. We did not have the opportunity to measure this. Developed foundation deformation resulted in damages of low-pressure (NT) rotor and shaft sealing inside the low-pressure part. The accident rendered as necessary machines adjustments, additional measuring devices inside the machine and consistent monitoring of the TFS deformations using high-precision levelling method (HPL).

There are quite many even qualified persons who think that such robust foundation is so rigid that no significant deformations may occur. To give you an idea how big deformation of the TFS of such unit is caused only by the load of water in condenser and steam area refer to fig. 1. The condition was recorded only couple hours after the condenser was filled with water.

Example of the TFS deformation development at 200 MW unit caused by continuous additional load on foundation during the unit reconstruction is shown in fig. 2.
Shape of deformation was recorded shortly after the individual parts of turbine had been installed. Already this measurement revealed that shapes of the TFS longitudinal axis and the turbine-generator unit axis were materially different. Over time, obviously, this deformation will be gradually increasing in extent.

Deformations caused by operational conditions on various types of foundations.

Deformations resulting from operation are significantly greater than deformations caused by static strain of foundation (3 times in average). This also corresponds with the ratio of the turbine-generator unit wear and tear, augmented by number of start-ups during a year.

Example of correlating deformations of a 200 MW F-TGU system, the most frequent setup in the Czech Republic, is shown in fig. 3a,b. This setup features traditional foundations, i.e. reinforced concrete structure where the TFS consists of prefabricated parts, or monolithic reinforced concrete foundation slabs and steel masts used in newer power plants.

Structural arrangement of turbine bodies and bearing support stands is designed in such a way to eliminate disruptions to rotor-stator concentric position of individual turbine bodies. Turbine-generator unit, however, is placed on a foundation, which deforms during operation due to substantial changes of temperature and other conditions. Foundation deformations result in uneven vertical shifts of bearing support stands and negatively affect changes of the turbine-generator unit rotation axis shape. Individual partial deformations of TFS and other impacts superimpose and correlate with deformations of rotation axis.

The most important impacts on this deformation type development are the turbine-generator unit and related technology arrangement within the machine room – fig. 3c. These include the crosswise arrangement of turbine-generator unit where, from the high-pressure (VT) part side, the foundation and masts are warmed by adjacent heating room, while at the same time they are cooled in the exciter area by the machine room external wall, especially when the personnel makes their presence in machine room more pleasant by opening its windows, and more so when the turbine-generator unit has a south-north orientation. Another source originating the foundation deformations is placement of turbo supply adjacent to high-pressure part of the turbine-generator unit. Tilts and deflections of cross beams (fig. 3d) deform rotation axis both in horizontal (fig. 3e) as well as in vertical direction (fig. 3a).

Deformations caused e.g. by inconsistent maintenance methods, installation errors, etc.

Exploitation of findings obtained by outputs of deformation development in the F-TGU systems measurements using geodetic survey measurement methods is presented on examples of two power plants featuring identical type of both foundations and technology. Locations vary only in geological subsoil, which introduces only minimum differences in the foundation deformation extent.

Fig. 4 shows the difference in the extent of rotation axis deformation when remedial measures are implemented systematically based on results of deformation development measurements of the F-TGU systems (such as the rotor setup alignment taking into account operational conditions of TFS deformation, allowing necessary thermal dilatation of condensers in vertical direction but also implementation of controlled venting of the machine room, etc.) as opposed to persistent condition with conservative approach, where especially the TFS deformed shape during operation is ignored. Under normal operational conditions no crash is probably imminent owing to great safety reserves of produced turbine-generator units. However, if other adverse operational impacts accumulate, damage to the rotor setup or even a serious accident are not out of the question.

As an example of installation error causing the turbine-generator unit rotation axis deformation we may present another case – a 1000 MW unit, fig. 5. Common output piping from the high-pressure (VT) part is fixed by means of so-called fixed point against horizontal shifts. In this case, however, temperature dilatation was made impossible in vertical direction. Fig. 5 shows how this error projected itself into deformation of rotor setup.

Consequences of deformation development in foundations of turbine-generator unit to the rotation axis may be eliminated by suitable remedial measures. Such measures allow the turbine-generator unit to operate under more favourable conditions, which can significantly contribute to lower maintenance costs while also prolonging the regular service intervals and overall system lifecycle. Measurements of the deformation development in F-TGU systems may provide a substantial contribution, as documented by fig. 7 and 8 in the section below.

Example of exploitation of findings obtained by deformation development monitoring in the F-TGU systems as it is applied in operation at a 1000 MW unit. Requirement for described re-alignment of rotor setup occurred as a result of the TFS gradual creeping and it should also allow to readjust centricity of the water-flowing part of the machine.

Three types of information are used for the turbine-generator unit rotation axis re-alignment: results of the measurement using the high-precision levelling method during continuous operation and after the turbine is shut down for fuel replacement (cold state, loaded by operational materials, uncaged); results of couplings hooking in the same terms; and records of the lower clearances between the low-pressure rotors and RK from the moment the power starts decreasing until the cold state is reached. For assessment, changes from the last service are compared and the axis re-alignment is proposed (if necessary) to ensure that the lower clearances in low-pressure parts and the axis alignment would respect formerly measured changes between the cold and hot states.

Important principle of this type of adjustments to the rotation axis alignment with respect to requirements for centricity is the alignment optimization for operation. TFS deformation will occur always – it is necessary to take it into account and "learn how to live with it".

Average differences in the top foundation slab shape in cold state and stabilized operational state may be determined either by the high-precision levelling or by calculation. While it is in fact possible to calculate operational deformation using a model, results are rather uncertain especially due to difficulties with defining the temperature field.

In order to properly exploit the results of deformations development monitoring at other power plants units in operation, described facts must be assessed on a case-by-case basis. The reason is that the shape of foundation deformation, and therefore also of the turbine-generator unit rotation axis, vary substantially between the cold and operational states. This however does not mean that similar approach cannot be used for the turbine-generator unit rotation axis alignment at any type of turbine-generator unit and foundation structure – see fig. 4, showing approaches in two different power plants.

Deformations of other power plants components (structural objects).

Deformations of structural objects are commonly caused by geological, geotechnical and other influences but also by fluctuations of underground water level, loads imposed by surrounding objects and dumping sites, road traffic, etc.

Fig 6. shows an example of foundation deformations of cooling towers. Obviously a geotechnical disruption causes a strange character of the foundation setting, which could compromise their reliable operation.

Cooling towers lifecycle is threatened also by other reasons. For instance, temperature dilatation itself in the summer-winter interval reaches ±5-8 mm in radius; in perimeter the dilatation is ±3-4.5 cm. If we add impacts of the cooling tower operation rendered to the cooling tower enclosure, resulting values are substantially higher. Such changes of the cooling tower perimeter cause cracks followed by reinforcement corrosion, and along with the foundation deformation their lifecycle is compromised as well.

Conclusion.

All examples mentioned above may offer inspiration to accept measures aimed to enhance lifecycles of various components, mainly of technological character, installed in power plants. Should the deformation development monitoring in F-TGU systems positively contribute to reliable operation, it must be performed within the frame of preventive regular checks of the machine. The reason is that the foundation deformations – and thus also deformations of the turbine-generator unit – keep increasing over time and therefore monitoring of their development cannot be performed only at random or even only after the damage is done and remedy is underway.

Actions performed in this sphere could reach higher quality levels if technical regulations are updated, such as ČSN 73 1020 – Designing foundations for rotating machines, or revised methodological guidelines for deformation development monitoring in F-TGU systems.

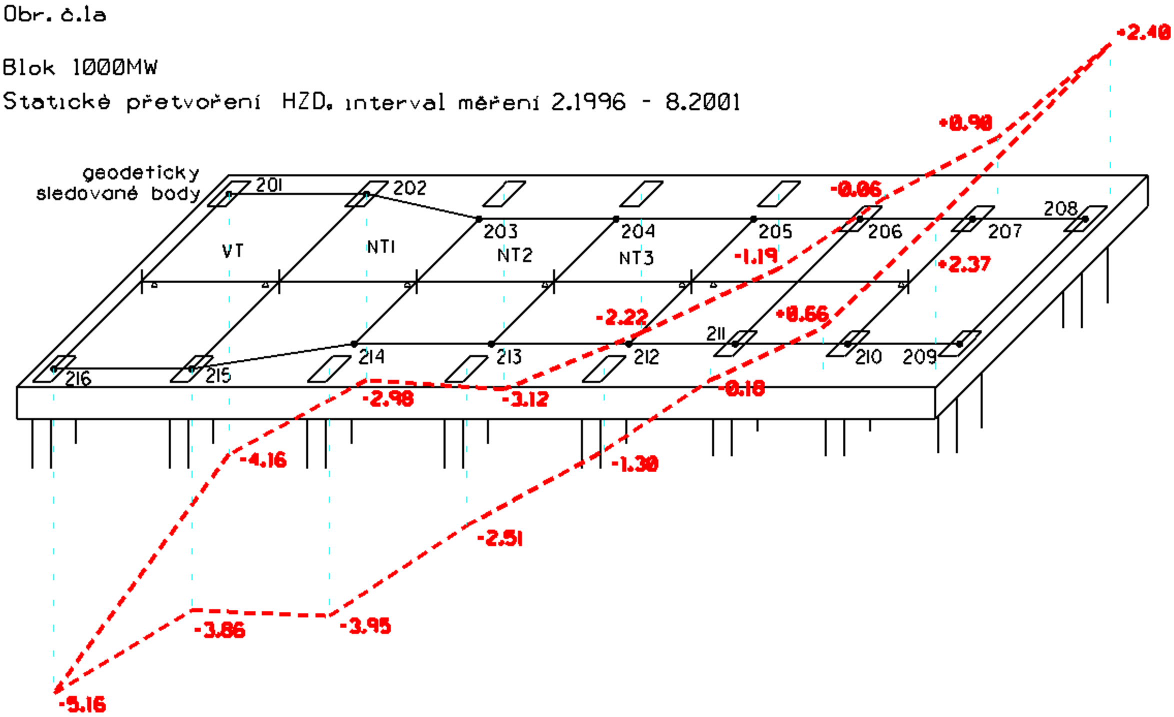
Experiences obtained from measuring deformations of turbine bodies and their centricity during trial installations are no less interesting as well. If the organizational board of next conference would consider this beneficial and if my health would allow, I would be pleased to present you results of these measurements next time.

Thank you for your attention and I wish you success in your endeavor aimed to enhance lifecycles of power engineering components in power plants – and good health.

Obr. č.1a

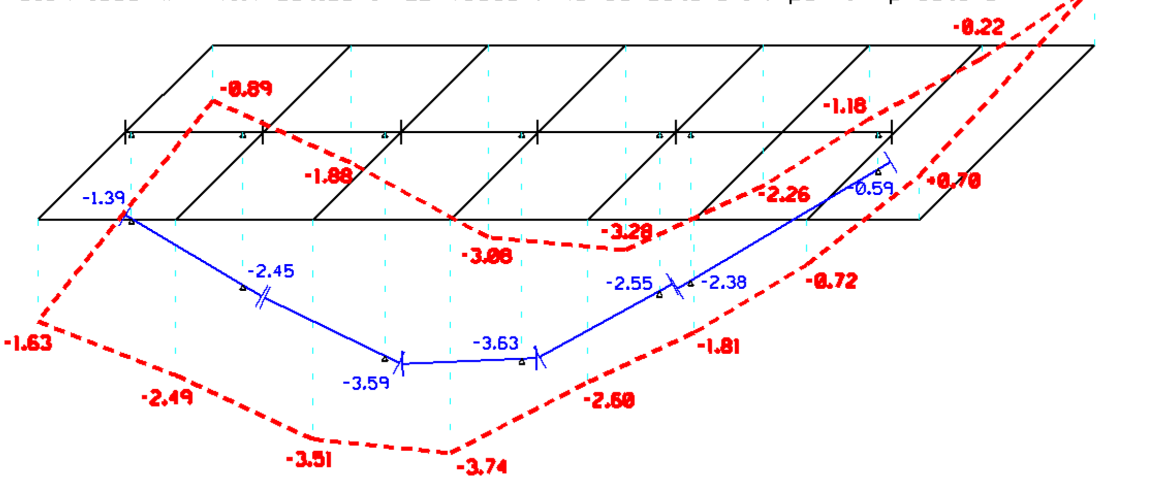
Blok 1000MW

Statické přetvoření HZD, interval měření 2.1996 - 8.2001



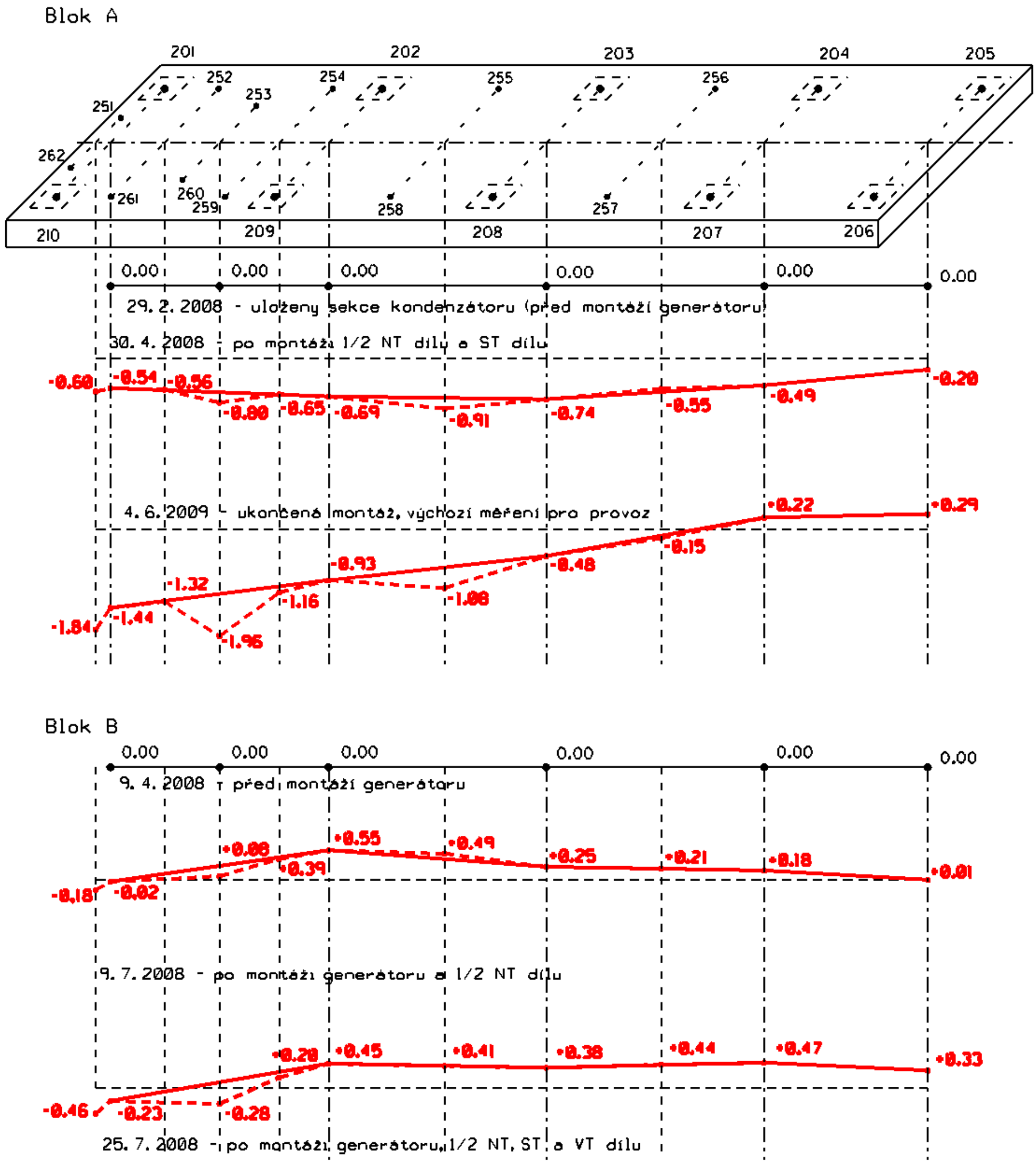
Obr. č.1b

Blok 1000MW - vliv zatížení HZD vodou v kondenzátoru i v parním prostoru



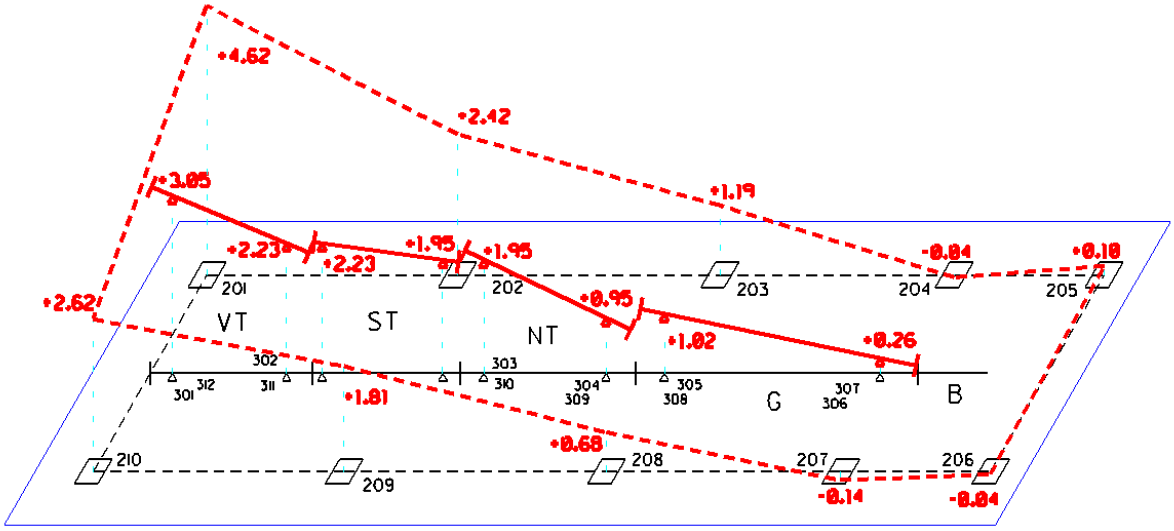
Obr.č.2

Blok 200MW - vliv přitěžování na deformaci základu v průběhu rekonstrukce



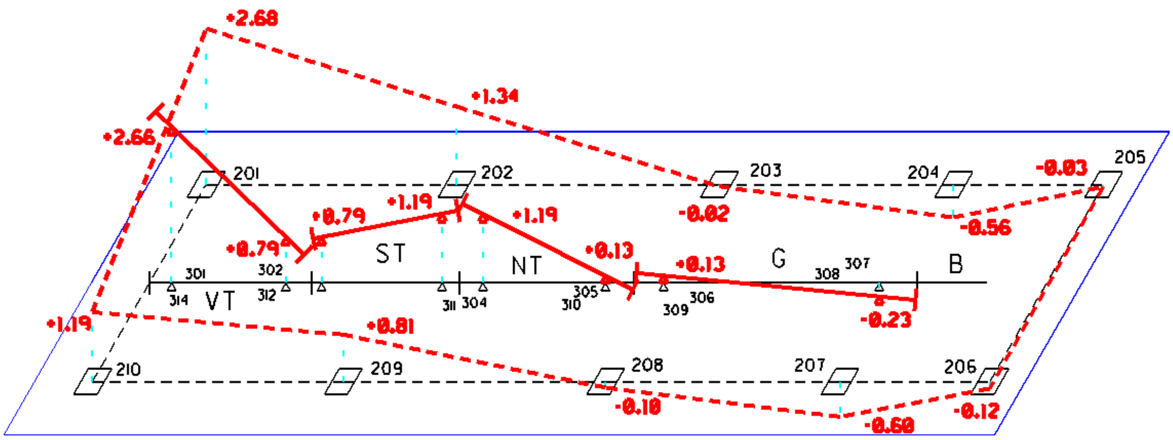
Obr.č.3a

Blok 200MW - základ tvoří žel. bet. konstrukce s ocelovými sloupy



Obr.č.3b

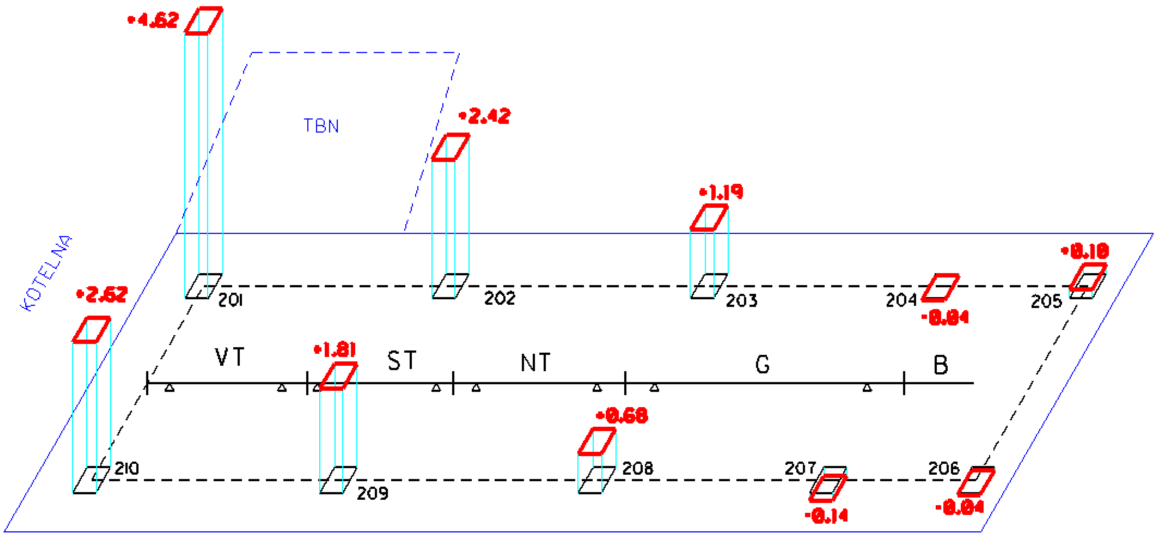
Blok 200MW - základ z prefabrikovaných dílů



Obr.č.3c

Blok 200MW - základ tvoří žel.bet.konstrukce s ocelovými sloupy

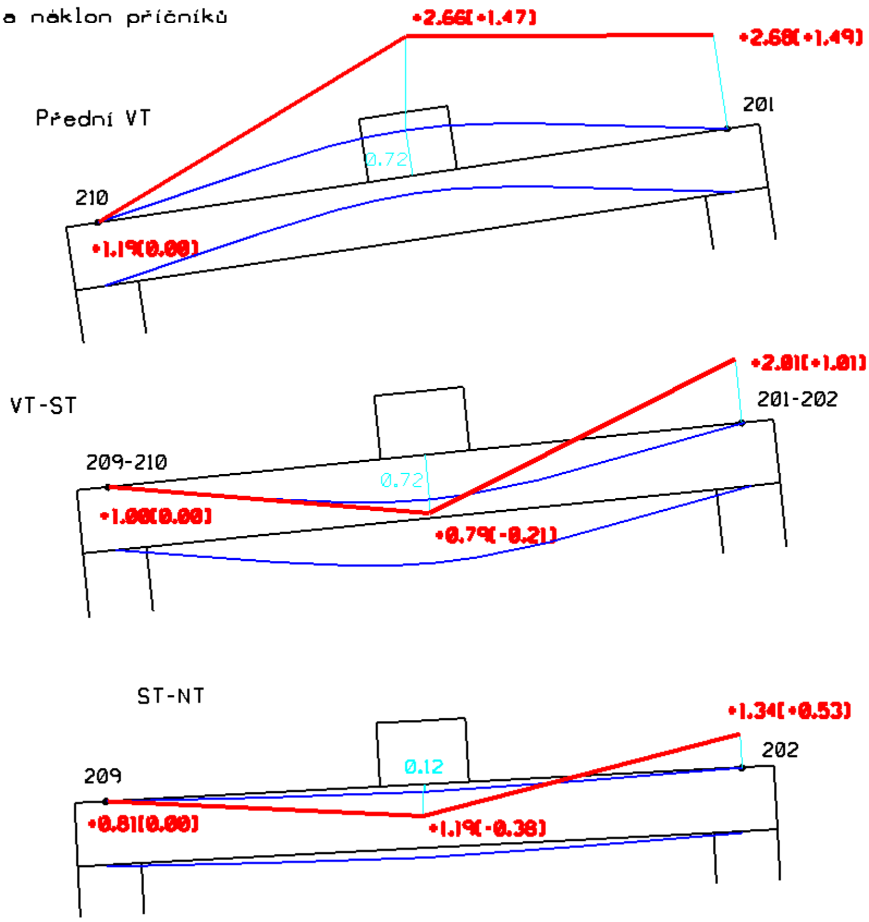
Dilatace sloupů vlivem změněného teplotního pole systému Z-TG



Obr.č.3d

Blok 200MW - základ z prefabrikovaných dílů

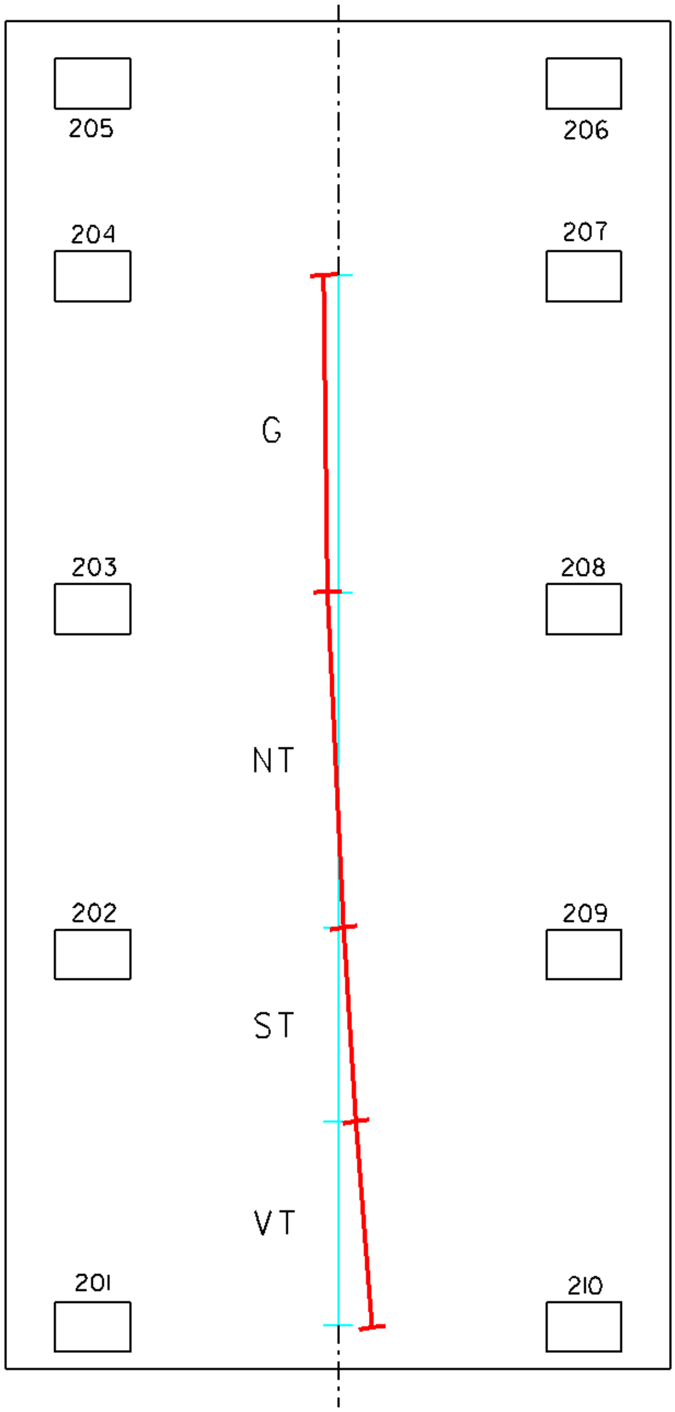
Průhyb a náklon příčníků



Obr. č.3e

Blok 200MW

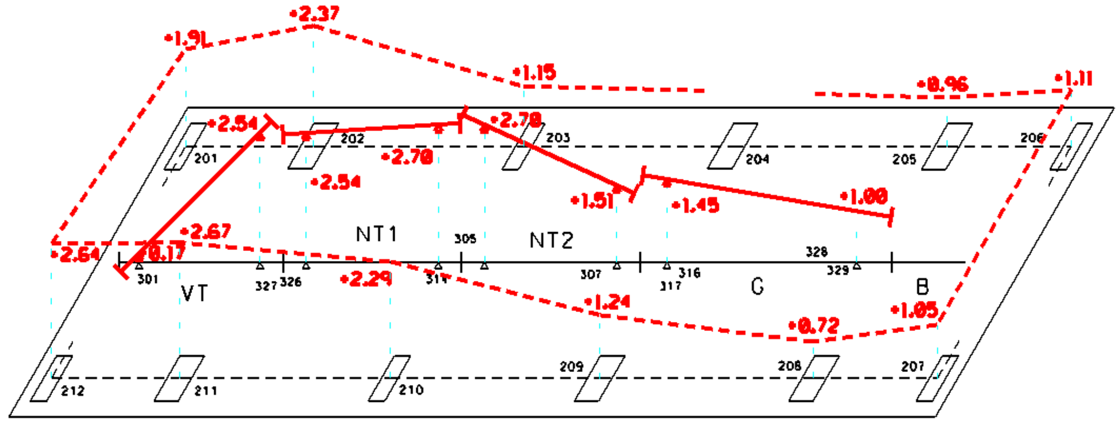
Horizontální posuny osy rotace za provozu



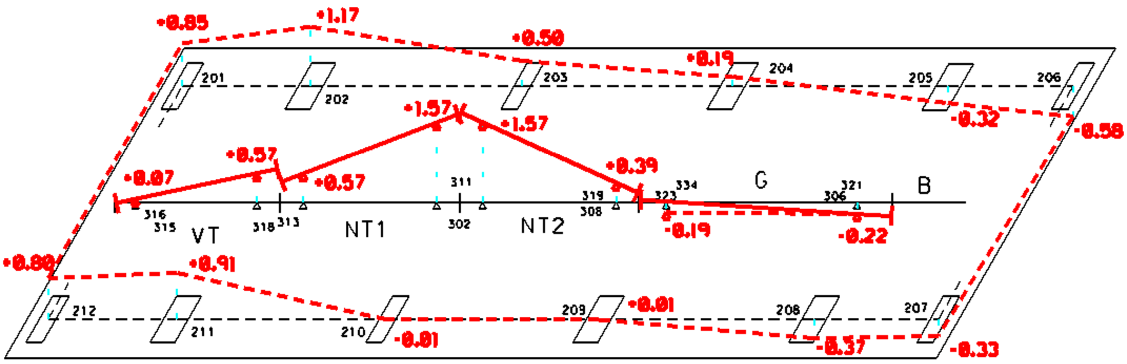
Obr.č.4a,b

Blok 220MW - Korelace deformace HZD a osy rotace - za provozu

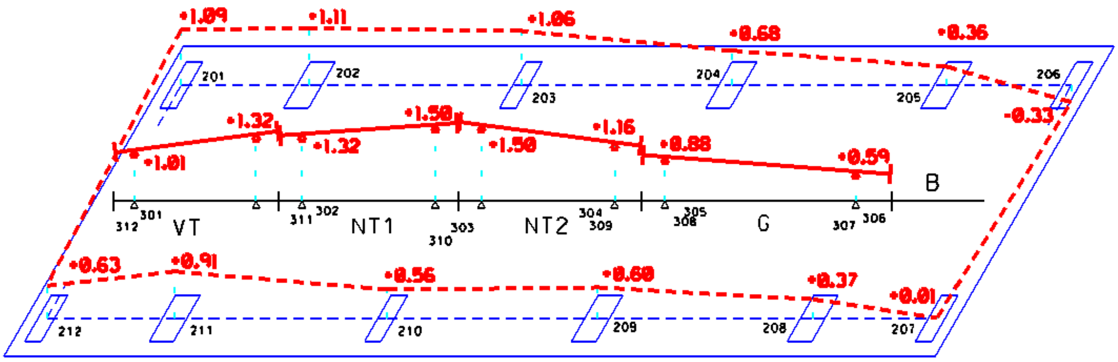
Elektrárna č.1



Elektrárna č.1

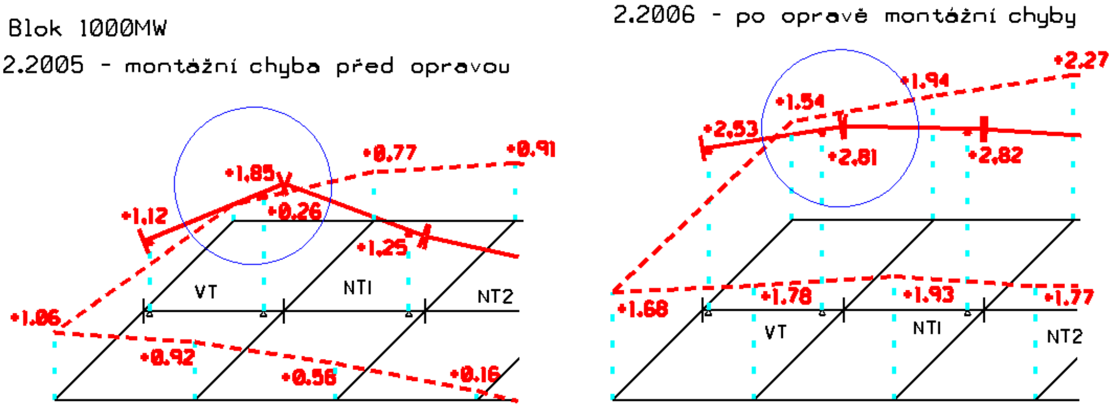


Elektrárna č.2

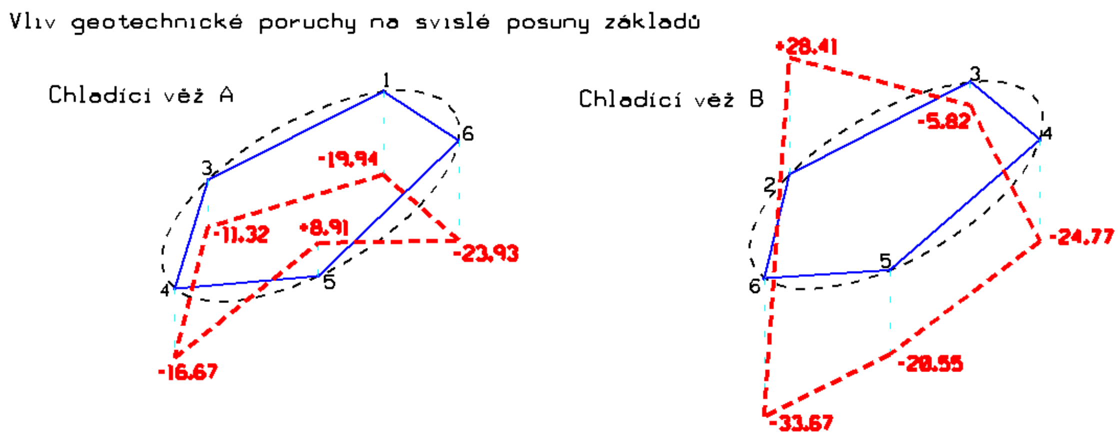


Měřítko svislých posunů 10:1, hodnoty uvedeny v milimetrech

Obr. č.5



Obr. č.6

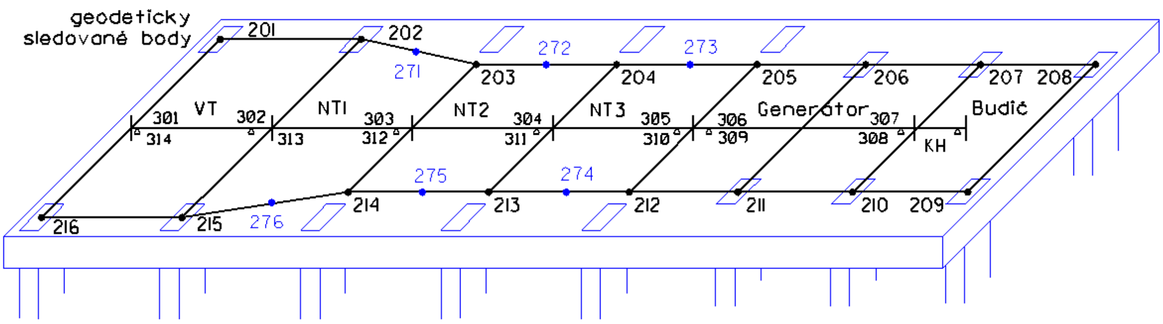


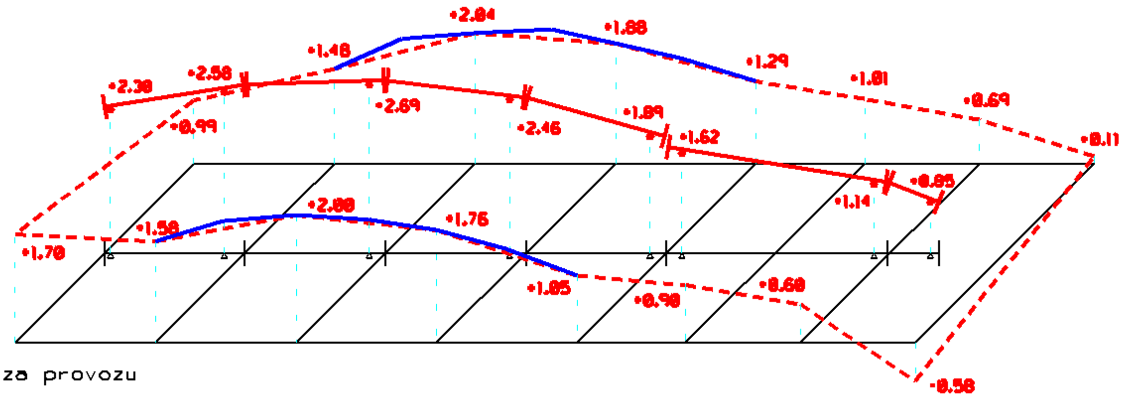
Hodnoty posunů udány v milimetrech

Obr. č.7

Blok 1000MW

Korelace deformace HZD a osy rotace



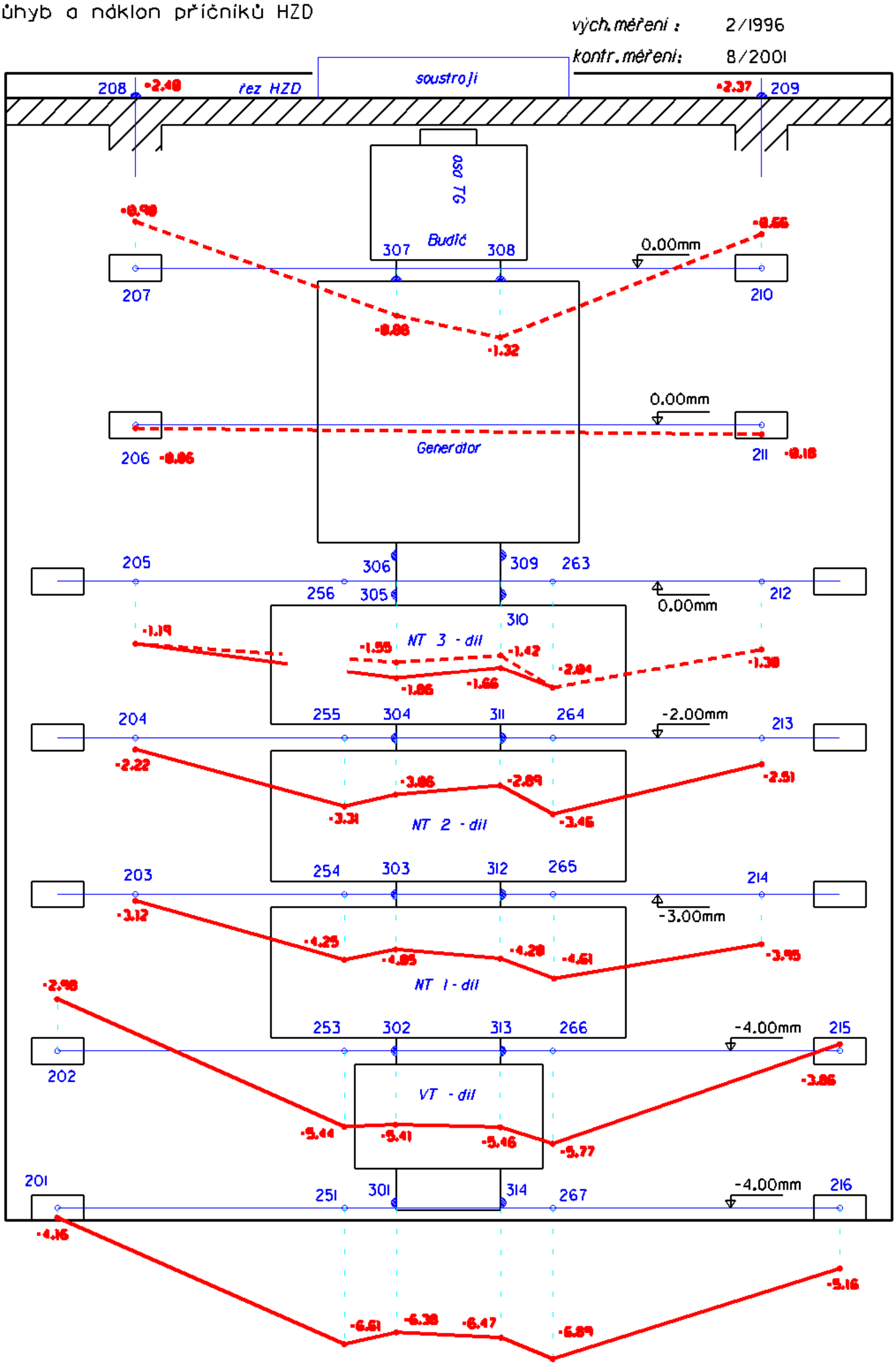


za provozu

Obr. č.8

Blok 1000MW

Průhyb a náklon příčníků HZD



Poznámky - hodnoty udány v milimetrech
- měřítko svislých posunů = 10:1

Obr. č.1a	Fig. 1a
Blok 1000MW	Unit 1000 MW
Statické přetvoření HZD, interval měření 2.1996 – 8.2001	Static strain of TFS, interval of measurements February 1996 – August 2001
geodeticky sledované body	points monitored by geodetic survey methods
	VT = high-pressure part
	NT = low-pressure part
	TFS = top foundation slab
Obr. č.1b	Fig. 1b
Blok 1000 MW – vliv zatížení HZD vodou v kondenzátoru i v parním prostoru	Unit 1000 MW – impact of water load in condenser and in steam area to TFS
	TFS = top foundation slab
	VT = high-pressure part
	NT = low-pressure part

Obr. č.2	Fig. 2
Blok 200 MW – vliv přitěžování na deformaci základu v průběhu rekonstrukce	Unit 200 MW – impact of additional load to foundation deformation during reconstruction
Blok A	Unit A
29.2.2008 – uloženy sekce do kondenzátoru (před montáží generátoru)	Feb 29, 2008 – condenser sections installed (prior installation of generator)
30.4.2008 – po montáži 1/2 NT dílu a ST dílu	Apr 30, 2008 – after installation of 1/2 of NT part and ST part
4.6.2009 – ukončená montáž, výchozí měření pro provoz	Jun 04, 2009 – installation completed, initial measurement for operation
Blok B	Unit B
9.4.2008 – před montáží generátoru	Apr 09, 2008 – prior installation of generator
9.7.2008 – po montáži generátoru a 1/2 NT dílu	Jul 09, 2008 – after installation of generator and 1/2 of NT part
25.7.2008 – po montáži generátoru, 1/2 NT, ST a VT dílu	Jul 25, 2008 – after installation of generator, 1/2 of NT part, ST part and VT part
	VT = high-pressure part
	NT = low-pressure part
	ST = middle-pressure part

Obr. č.3a	Fig. 3a
Blok 200 MW – základ tvoří žel. bet. konstrukce s ocelovými sloupy	Unit 200 MW – foundation made of reinforced concrete structure with steel masts
	VT = high-pressure part
	NT = low-pressure part
	ST = middle-pressure part
	G = generator
	B = exciter
Obr. č.3b	Fig. 3b
Blok 200 MW – základ z prefabrikovaných dílů	Unit 200 MW – foundation made of prefabricated parts
	VT = high-pressure part
	NT = low-pressure part
	ST = middle-pressure part
	G = generator
	B = exciter

Obr. č.3c	Fig. 3c
Blok 200 MW – základ tvoří žel. bet. konstrukce s ocelovými sloupy	Unit 200 MW – foundation made of reinforced concrete structure with steel masts
Dilatace sloupů vlivem změněného teplotního pole systému Z-TG	Dilatation of masts as a result of changed temperature field of the F-TGU system
	TBN = turbine
KOTELNA	HEATING ROOM
	VT = high-pressure part
	NT = low-pressure part
	ST = middle-pressure part
	G = generator
	B = exciter
Obr. č.3d	Fig. 3d
Blok 200 MW – základ z prefabrikovaných dílů	Unit 200 MW – foundation made of prefabricated parts
Průhyb a náklon příčníků	Deflection and tilt of cross beams
Přední VT	Front high-pressure part
	VT = high-pressure part
	NT = low-pressure part
	ST = middle-pressure part

Obr. č.3e	Fig. 3e
Blok 200 MW	Unit 200 MW
Horizontální posuny osy rotace za provozu	Horizontal shifts of rotation axis during operation
	G = generator
	VT = high-pressure part
	NT = low-pressure part
	ST = middle-pressure part

Obr. č.4a,b	Fig. 4a,b
Blok 220 MW – Korelace deformace HZD a osy rotace – za provozu	Unit 220 MW – Correlation of deformation of TFS and rotation axis – during operation
Elektrárna č.1	Power plant No. 1
Elektrárna č.2	Power plant No. 2
Měřítko svislých posunů 10:1, hodnoty uvedeny v milimetrech	Scale of vertical shifts 10:1, values listed in millimeters
	VT = high-pressure part
	NT = low-pressure part
	ST = middle-pressure part
	G = generator
	B = exciter

Obr. č.5	Fig. 5
Blok 1000 MW	Unit 1000 MW
2.2005 – montážní chyba před opravou	Feb 2005 – installation error prior remedy
2.2006 – po opravě montážní chyby	Feb 2006 – installation error remedied
	VT = high-pressure part
	NT = low-pressure part
Obr. č.6	Fig. 6
Vliv geotechnice poruchy na svislé posuny základů	Impact of geotechnical disruption on vertical shifts of foundations
Chladicí věž A	Cooling tower A
Chladicí věž B	Cooling tower B
Hodnoty posunů udány v milimetrech	Values of shifts listed in millimeters

Obr. č.7	Fig. 7
Blok 1000 MW	Unit 1000 MW
Korelace deformace HZD a osy rotace	Correlation of deformation of TFS and rotation axis
geodeticky sledované body	points monitored by geodetic survey methods
	VT = high-pressure part
	NT = low-pressure part
Generátor	Generator
Budič	Exciter
za provozu	in operation

Obr. č.8	Fig. 8
Blok 1000 MW	Unit 1000 MW
Průhyb a náklon příčníků HZD	Deflection and tilt of TFS cross beams
vých. měření: 2/1996	initial measurement: Feb 1996
kontr. měření: 8/2001	checking measurement: Aug 2001
řez HZD	TFS cross-section
soustrojí	turbine-generator unit
osa TG	TGU axis
Budič	Exciter
Generátor	Generator
	VT = high-pressure part
	NT = low-pressure part
Poznámky	Notes
– hodnoty udány v milimetrech	– values listed in millimeters
– měřítko svislých posunů = 10:1	– scale of vertical shifts = 10:1