Problems of thermal stress in metal reinforcements of large-dimensional objects with elevated service temperatures

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Content

1. Problem

For the insulation of hot objects – especially large-dimensional ducts as found in nuclear power plants, flue gas desulphurisation and denitronisation systems –, it must be considered that reinforcing stiffeners on the duct wall always constitute thermal bridges. Two problems result:

- The increased thermal transmission through the thermal bridge leads to reduced temperatures at the inner surface of the duct wall. This may lead to going below the dew point temperature of the flue gas on that inner surface. This problem is not considered in this paper.
- With unacceptably high temperature differences between the inner and the outer edge of the stiffeners, thermal stress may result leading to distortion of profiles resulting in cracking of welded seams. For this reason, it is common to calculate maximum admissible temperature differences that are to be maintained through an appropriate construction and dimensioning of the insulation.

The limitation to the temperature differences demanded does not constitute a problem in steady-state service, i. e. with flue-gas temperatures not changing over time as long as the required insulation material coverage on the outside of the stiffeners – 1/3 s for stiffeners up to 100 mm, 2/3 s for stiffeners over 100 mm – is observed.

Difficulties, however, may occur in the non-steady-state service – where flue-gas temperature change over time as the installation is started up or shut down.

On starting up the installation, the temperature on the inner surface of the wall and the inner edges of the reinforcing stiffeners follows the increasing flue-gas temperature, whilst the outer edges of the stiffeners remain cold and the temperature there increases only after a considerable delay. This may lead to temperature differences substantially above those in steady-state service.

The magnitude of these “non-steady-state temperature differences” is dependent upon a variety of factors:

- The speed of temperature increase in the flue gas: the faster the installation started up, the higher the temperature difference.
- Size of the stiffeners: with big profiles and large masses, the temperature differences are higher than with small profiles.
- Shape of the reinforcing stiffeners.
- Thermal conductivity of the materials used.
- Thermal transmission conditions.

To lower the temperature differences, measures must be taken to allow for the movement of as much heat as possible through radiation and convection from the duct wall to the outer edge of the reinforcing stiffeners. This may be achieved – if technically feasible – by leaving an ample portion of the duct wall uninsulated.

These and other measures in the area of insulation are, however, of limited effect. With big reinforcing stiffeners, the steady-state temperature differences cannot be reduced to acceptable values even through “the best possible insulation”. Therefore, other measures – outside the control of the insulation trade – are required. Such measures could be e. g. to use several smaller stiffeners instead of one large one, or to reduce the rate of temperature increase when starting up the installation.

2. Principal considerations concerning the non-steady-state temperature distribution in reinforcing stiffeners

Depending upon the individual design, the temperature in reinforcing stiffeners is influenced by the shapes, and the appropriate insulation material design values.

Some observations of principle can be made for the design examples given in Figures 1 and 2.

The simple reinforcing fin (steel sheet; generally smaller than 100 mm) would generally have roughly equal temperatures at the inner and outer edges, providing the insulation material coverage d was sufficiently extensive (see chapter 1). In this case, no elevated thermal stress occurs. The “dew point temperature problem” on the inner surface of the duct wall, however, must also be considered in this case.

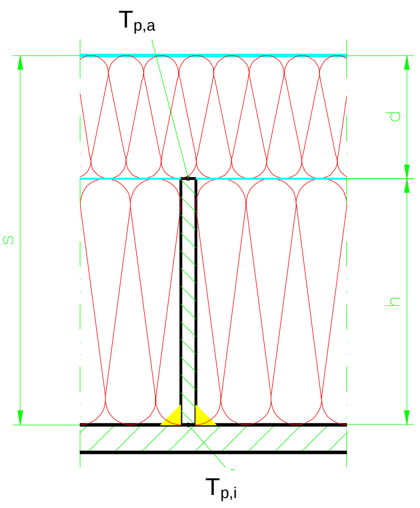

Figure 1

Contrary to this example, the temperature on the outer edge of the normally bigger I-profile (double T-profile – generally with webs exceeding 100 mm) definitely be lower than of the inner edge, since bigger masses must be heated on the outer edge and the heat transport requires more time due to the length of the web.

Frequently, the insulation contractor is required to prove mathematically temperature differences to be expected – normally calculated against known warming-up conditions in the start phase of the installation. Such calculations can be computed with numerical procedures such as the finite difference or the finite element method. However, it must be remembered that with these methods the thermal transmission inside the stiffener can be calculated satisfactorily exact, however, assumptions must be made regarding the movement of heat through radiation and convection, the precision of which is frequently very difficult to assess. This applies especially to radiation. Here, the surface conditions of the duct wall and the reinforcing stiffener are of decisive importance. They are not known to the insulation contractor with the precision required. Therefore, the declaration of warranties on the basis of such calculations should be cautioned against.

3. Example

For the insulation following the surface of the profile IPE 360 as in Figure 2a, some results of finite element calculations are given below. Figure 3 shows the temperature increase over time at an uninsulated duct wall, the inner and outer edges of the reinforcing flange when the warming-up transient is 1,6 K/min and 0,4 K/min.

The maximum occurring temperature differences for a profile IPE 400, insulated according Figure 2a, is given for different warming-up transient and for the steady-state service in Table 1.

Table 2 shows the maximum temperature differences for I-profiles, insulated with “air gaps” according to Figure 2b.

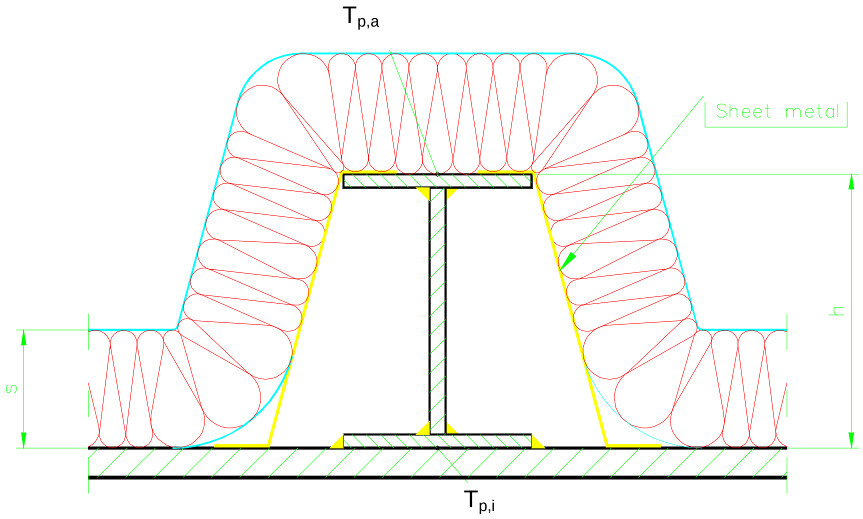

Figure 2a: Insulation following the surface

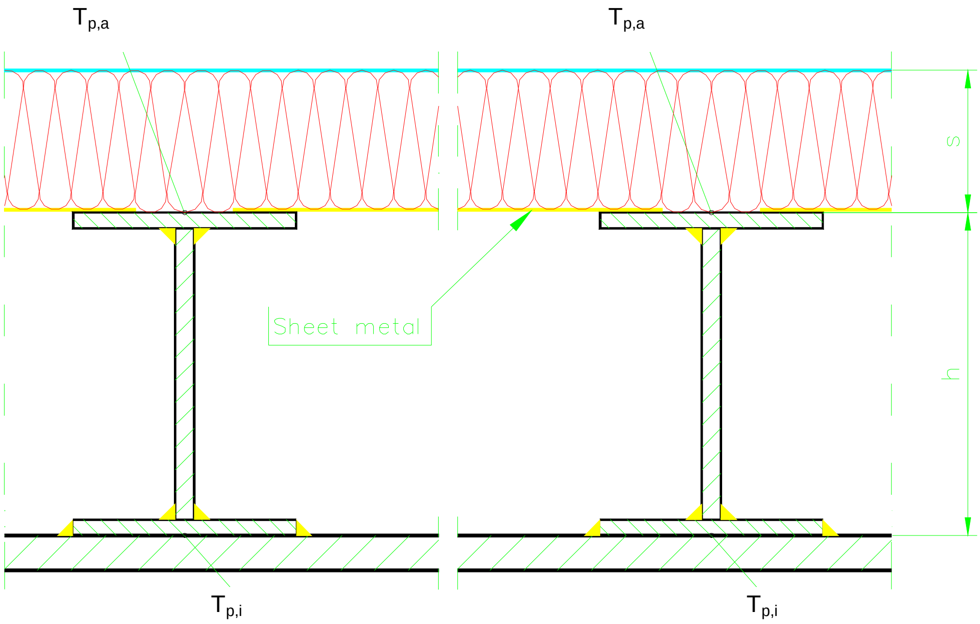

Figure 2b: Insulation with air gap

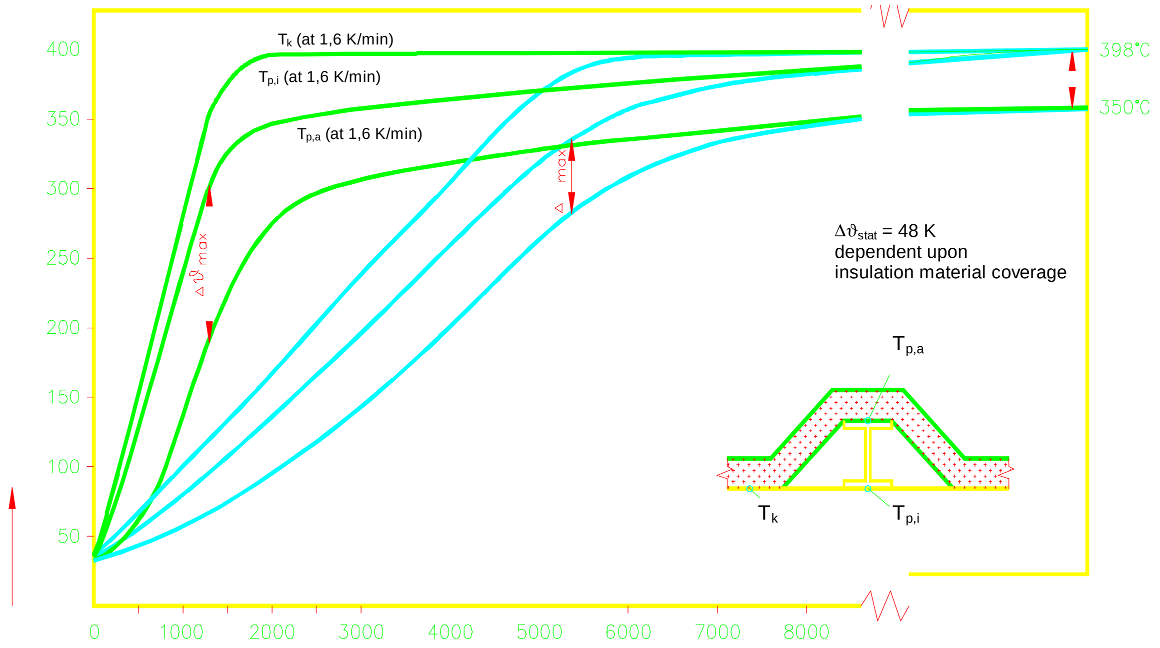

Figure 3: Temperature increase over time with an IPE 360 profile
Warming-up transient 0,4 K/min and 1,6 K/min

STEADY-STATE		NON-STEADY-STATE Initial temperature = +40 °C		
Profile	Temperature difference in stiffeners = $\Delta\vartheta$ [K]	Profile	Temperature differences in stiffeners = $\Delta\vartheta$ [K]	Initial temperature K/min (temperature transient)
IPE 400	about 35	IPE 400	130	1,6
		- " -	100	0,8
		- " -	80	0,4
		- " -	50-60	0,2

Table 1: Temperature differences in stiffeners with insulation following the surface (according to Figure 2a)

STEADY-STATE		NON-STEADY-STATE Initial temperature = +40 °C		
Profile	Temperature difference in stiffeners = $\Delta\vartheta$ [K]	Profile	Temperature differences in stiffeners = $\Delta\vartheta$ [K]	Initial temperature K/min (temperature transient)
IPE 400	about 10	IPE 400	about 50-60	1,6
		- " -	about 40	0,8
		- " -	90	2,0
IPE 400	about 10	IPE 460	75	1,6
		- " -	50	0,8
HEA 300	about 10	HEA 300	57	1,6
		- " -	45	0,8
IPE 370	about 10	IPE 370	53	1,6
		- " -	34	0,8
IPE 300	about 10	IPE 300	45	1,6
IPE 270	about 10	IPE 270	42	1,6

Table 2: Temperature differences in flanges with "air-gap" insulation (according to Figure 2b)

The results show that especially whilst warming up the installation, critical stress maxima must be expected. The warming-up gradient has decisive influence here.

A comparison of the two designs considered here makes it obvious that the "air-gap" insulation compared to the surface-following insulation results in smaller temperature differences for both the steady-state and the non-steady-state conditions. These observations, however, only hold true when uncontrolled convection influence can be prevented.

4. Conclusions

For the insulation of large-dimensional hot objects, special thermal condition considerations are required. Additionally, investigation of the possible deformation in the stiffeners as a result of temperature differences is needed. This applies specifically to non-steady-state service conditions such as start-up and shut-down phases and accidents.

A mathematical proof of the maximum occurring thermal stresses in the steel construction of an object is not within the area of responsibility of the insulation contractor. The static system selected and the static and dynamic stresses to be born by the construction are in the area of responsibility of the installation contractor.

Nevertheless, this problem should be addressed when discussing contracts and the builder should be made aware of it. It could be possible that there is a duty to caution against possible damages, if the thermal stresses to be expected as result of the layout and size of the reinforcements and the temperature differences to be expected could lead to damages.

In critical cases, the necessity may even occur to ensure an even distribution of heat at the outer edges of the reinforcement in the warming-up phase of the installation by installing an extra heating system.

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