

James Walker Townson

Problems & Solutions with Expansion Joints in Gas Turbine Exhaust Systems

A white paper presented by
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1. INTRODUCTION

Expansion Joints have been installed on Gas Turbine exhaust ducts since they were first introduced for Power Generation applications. Expansion Joints are required to isolate the delicately balanced turbine from the stresses induced by thermal movements and vibration within the duct system.

Recent developments in turbine technology have placed increasing demands on the expansion joint supplier to accommodate greater movements and ever higher temperatures. Though financial consideration is always a factor, reliability and trouble free service is always the ultimate goal for both the end user and the expansion joint supplier.

Unfortunately, the most competitively priced product does not necessarily guarantee that these goals are achieved. Expansion joints are an integral part of the exhaust system, the reliability of which is as important as the turbine itself. Failure in either results in shut down of the whole system until repairs can be effected.

Early expansion joint frame designs were based on the typical coal fired power station styles with slight modifications. In recent times specific design principles have been incorporated to improve performance and life expectancy.

Expansion joint manufacturers' individual designs have been developed and tested over many years.

2. BASIC DEFINITIONS AND CONFIGURATIONS

Designs vary from one supplier to the next but generally there are three basic configurations as shown in figures 1,2 &3.

- HOT TO HOT
- HOT TO COLD
- COLD TO COLD

Although designs may vary slightly there are basic principles that must be followed to ensure a trouble free life for the expansion joint. To avoid differential expansion at the connecting flanges for example, it is recommended that compatible materials be used for these areas to prevent inducing stress. The internal and external insulations should be designed to ensure temperatures remain even across this boundary.

Figures 1, 2 &3 are typical of the earlier designs. As many of these joints remain in existence today, their limitations and problems are discussed in detail within this document.

As a result of financial and operational constraints Gas Turbine stations often operate for "peak loading". This increases the number of starts and stops the system must accommodate which in turn causes fatigue in the mounting frames due to cyclic stress. To overcome this problem James Walker Townson has developed a series of frame designs, which can accommodate the required stress of a high cyclic life; see figs 1A, 2A and 3A

FIG 1
Hot to hot flange configuration

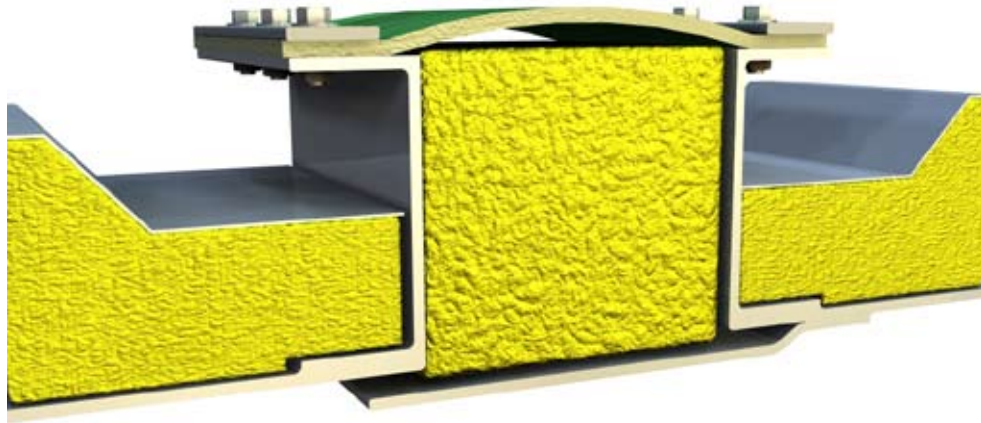
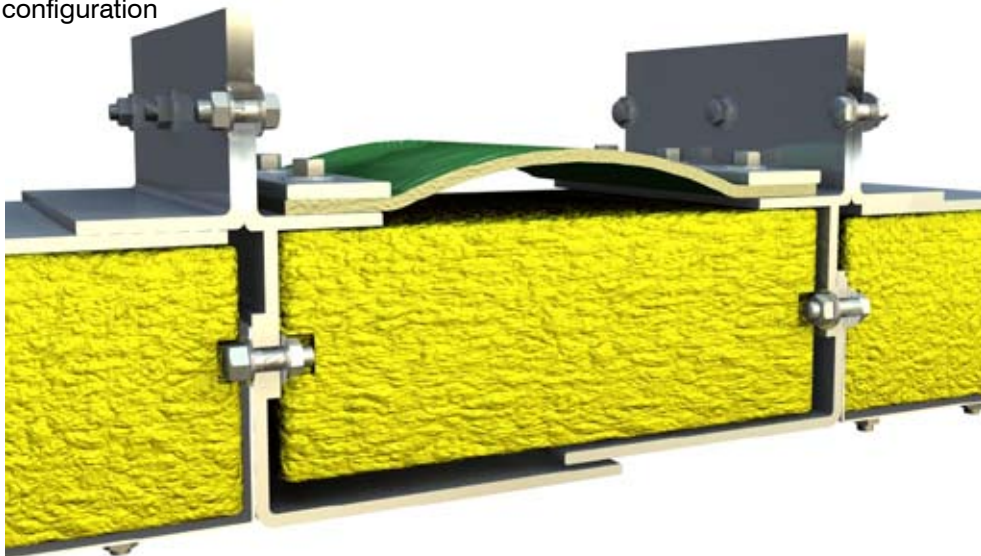


FIG 2
Hot to cold flange configuration



FIG 3
Cold to cold flange configuration



Figures 1A, 2A & 3A show the current design for each of the three joint formats. These incorporate features that eliminate many of the problems encountered with the older styles discussed in this document and have been included to show how developments have progressed.

FIG 1a
Gas turbine expansion joint profile
Hot to hot flange configuration

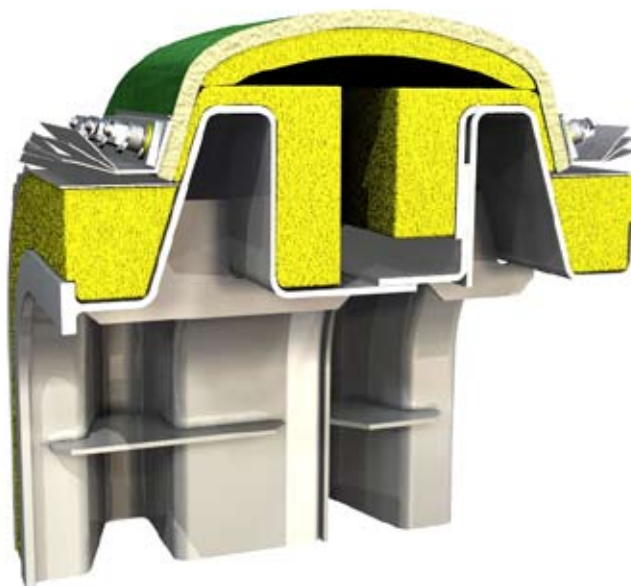


FIG 2a
Gas turbine expansion joint profile
Hot to cold flange configuration



FIG 3a
Gas turbine expansion joint profile
Cold to cold flange configuration



3.0 DESIGN PRINCIPLES

3.1 Composition

Fabric expansion Joints are designed to isolate the turbine from the thermal movements and vibration of the exhaust system and eliminate transmitted loads to the turbine outlet flange. This is achieved by utilising flexible elements that are capable of withstanding the high temperature and pressure fluctuations encountered during operation, whilst providing the flexibility of movement required and still retain both gas and heat.

The composition of the expansion joint varies between manufacturers, but each will contain an impervious gas barrier within the structure. This barrier is normally based on a PTFE type membrane having a temperature limitation of around 250-265°C. The inner layers of the expansion joint comprise a number of insulation layers designed to reduce the internal temperature to a level that does not exceed the recommended operating temperature for the gas barrier.

Expansion joint flexible elements are generally constructed as follows:-

- Outer Membrane - Weather resistant and mechanical protection layer.
- Gas Barrier - Gas barrier usually PTFE based.
- Thermal Barrier - Layers of fabric or insulation felts.
The thickness and composition of these layers is dependent on the individual supplier and thermal reduction required.

The flexible element of the expansion joint should be designed to accommodate the full gas temperature without additional insulation. However it is common practice to include an internal insulation pillow for the following reasons:-

- Reduces fluttering of the flexible element.
- Reduces noise transmission.
- Provides additional thermal insulation and improves system efficiency.

3.2 Advantages of Fabric Expansion Joints over Metallic

- Greater movement capability for reduced installed length.
- Maintenance friendly.
- Absorbs radial growth without stress.
- Accommodates lateral offset in a single joint,
- Significant reduction in transmitted loads between duct ends/turbine nozzle.

4. PROBLEMS AND SOLUTIONS

4.0 Support Frame Design

Modern design principles (FIG 1A, 2A & 3A) prevent large temperature differentials occurring within the frame and reduce internal stress accordingly. Designs have been developed using Finite Element Analysis to provide confidence in addressing thermal profile, thermally induced stress/strain and fatigue analysis.

4.1 Support Frame Damage

4.1.1. Cracking

Gas turbine exhaust systems are subject to rapid temperature increases from ambient to operational; particularly fig 1A Hot To Hot designs. This operational characteristic creates a number of problems, particularly for the earlier designs of framework.

The inner surface exposed to the full gas temperature heats rapidly and expands both radially and diametrically. The outer frame elements remain relatively cool during transition to stabilised running temperature and high internal stresses build up as a result. These stresses concentrate at the corners where much fabrication has often been necessary in order to generate the corner profile. Cracking at the corners on rectangular ducts is often a consequence

As in many situations, compromise is necessary in order to achieve the best result. In this case the up-stand of the frame is critical. From an operational viewpoint the up-stand should be as small as practical; however this would impose very high temperatures in the clamping area of the expansion joint, considerably reducing its life.

Higher up-stands favour the expansion joint with lower temperatures in the clamping area but higher induced internal stresses within the frame and resultant damage.

As a result of the temperature differentials, rectangular frames distort as shown in Fig 4. The optimum up-stand height for these earlier design frames has proven to be between 100 and 150mm. However this remains sufficient to produce cracking if precautions are not taken within the design concept. Finite element analysis and calculations combined with on-site experience has enabled us to develop features within the corner which prevent cracking.

Welds, which are potential weakness, have been removed and sited away from the high corners stiffened. These modifications can be applied to existing frames in-situ during maintenance periods to improve performance if the cost of up- grading to current design principles is prohibitive.

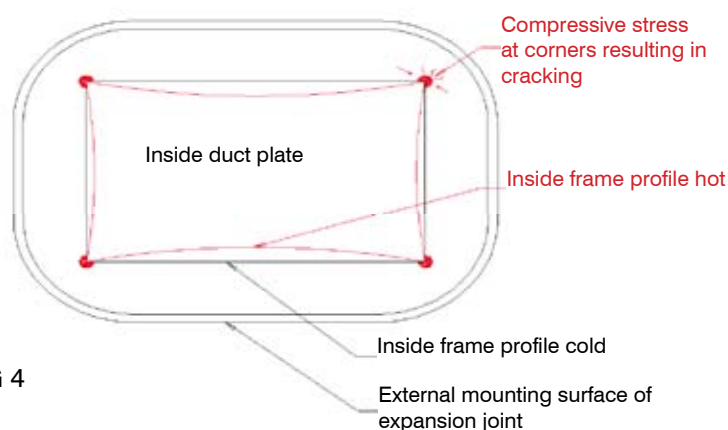


FIG 4

4.1.2 Distortion

Deflection within the frame, as detailed above, coupled with the thermal shock to the inside faces of the framework and the welding attachment of internal sleeves, may result in buckling and or clashing of the internal sleeves. This may cause failure of the weld and detachment of the sleeve.

The internal sleeves are vital components for the successful operation of the expansion joint and their loss could result in premature failure of the joint. Simple sleeves comprise a flat plate welded to the side wall of the expansion joint frame as shown in Fig 1. This design has operated successfully for many years on less thermally demanding applications in coal fired power stations. However, the greater demand placed on the system by Gas Turbines has shown weaknesses in this simple attachment method.

To provide flexibility in the internal sleeves, these should be installed as short sections of up to 1.5m in length with a gap between. The gap should be covered with a cover strip to prevent loss of bolster and or pinching. To produce a more secure attachment method, the inner sleeves were often bolted to the upstands as shown in Fig 3. The design length of the sleeve is also critical to the design. The longer the sleeve the greater the possibility of resonant vibration, which can also induce failure. Special consideration needs to be given to sleeves in excess of 250mm long.

4.2 Heat Damage

4.2.1. Lateral Movements

Development within the power generation turbine industry has lead to larger turbines, boilers and associated ductwork which in turn has given rise to greater thermal movements and generally more arduous operating conditions.

Due to financial restraints however, the number of expansion joints within the system has not been increased and the existing number of joints is expected to compensate for these greater movements. These movements have, in some cases, increased to the point where it is no longer practical to accommodate them in a single span expansion joint.

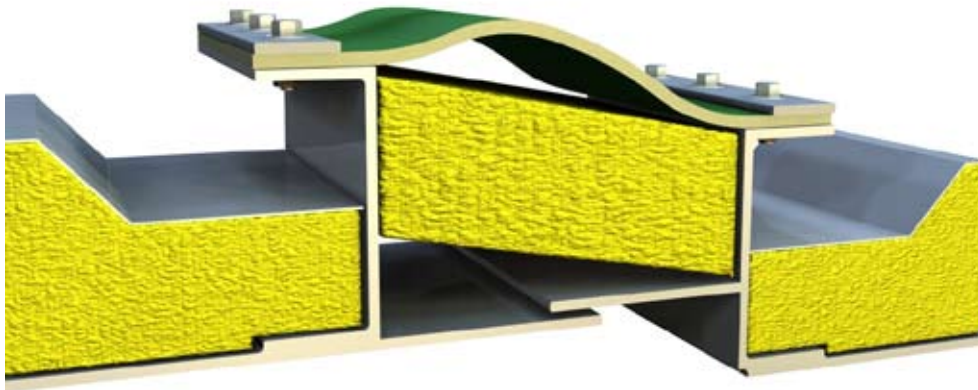
Typically, at the HRSG inlet, the expansion joint may see a lateral shear of between 150 and 200mm due to boiler growth. It would be irresponsible to offer a single span expansion joint for such large offsets when 65 to 70mm is considered the maximum permitted for such joints.

Large offsets produce creases or folds in the outer cover materials and the more pronounced these become the greater the stress on them, which can result in damage. Additionally, if air is trapped within these creases or folds, overheating of the membrane materials can occur, again reducing operational life,

The solution to this problem is to be found using two possible methods either individually or combined. These are as follows:-

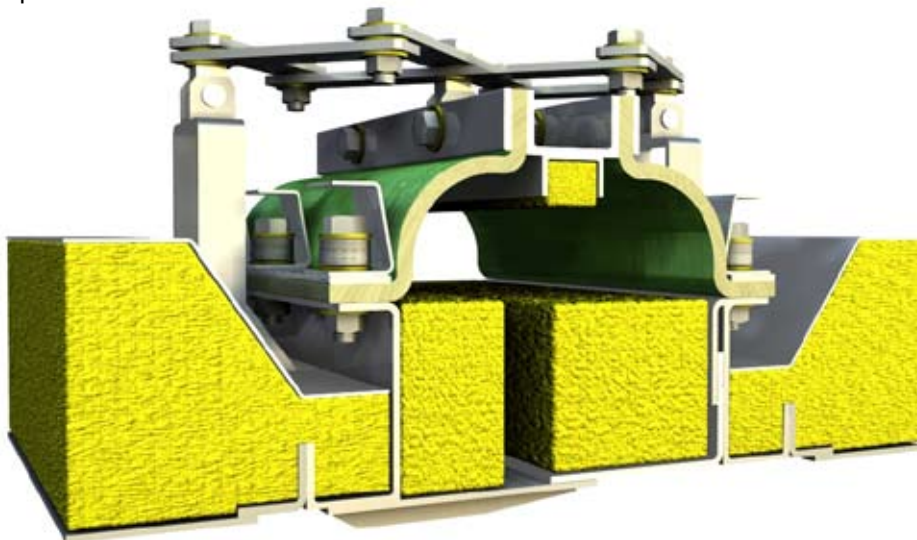
- A Preset the duct flanges so that the single expansion joint is exposed to +/- half the movement magnitude either side of the mean central position. (See Fig 5)

FIG 5



- B Install a double expansion joint with a pantograph control mechanism to equally divide the movement between both joints. (See Fig 6)

FIG 6
Typical double pantograph



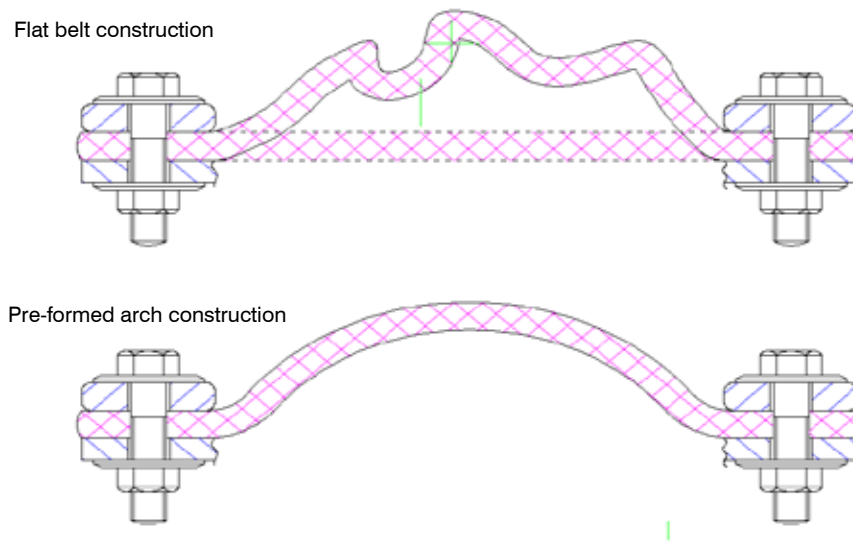
4.2.2 Axial Movement

In addition to the lateral movement conditions discussed above, axial movement also requires special consideration. When installed, conventional flat belt expansion joints have small creases or folds in the corners where distortion occurs. Under normal operating conditions with small axial movements these creases do not cause a problem. However, increased movements result in more pronounced creases, which again can reduce cooling to the outer membrane causing premature failure.

In order to prevent this occurring, when installed, the expansion joint should be constructed with a pre formed arch at the corners (See Fig 7). This configuration increases movement capacity to approximately 150mm. Movements in excess of this will require a double joint using a pantograph mechanism.

Excessive axial movements can also cause folding in the straights giving rise to abrasion on the clamp bar/bolt heads and overheating.

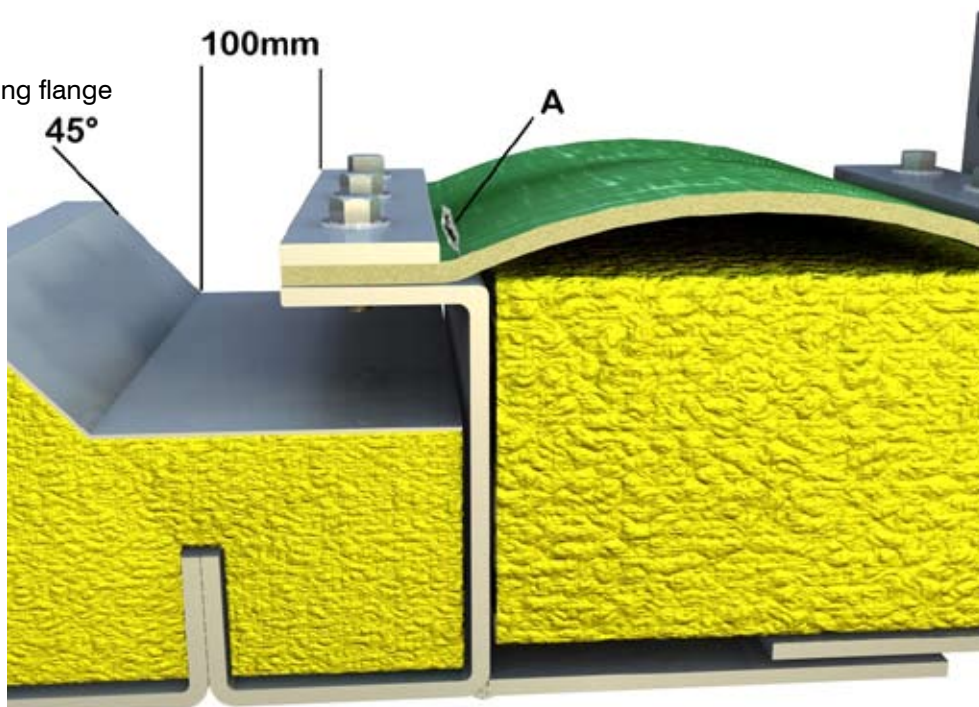
FIG 7



4.2.3 Mounting Flanges

In order to reduce stress levels within the steel structure, the mounting flanges of the expansion joint are designed to operate at high temperatures - as described in section 4.1.1. Unfortunately these high temperatures frequently cause failure of the expansion joint if the design of the external insulation is not considered carefully by the designer. (General recommendations for external insulation termination are shown in Fig 8)

FIG 8
Heat damage at mounting flange



The internal temperature of the frame is conducted to the clamping area and through the bolts to the clamp bar; increasing heat supply in the area of point A. This can burn the outer membrane causing fracture along the burned-out edge. Generally, at gas temperatures up to 400°C, conventional expansion joints operate satisfactorily without the need for any special consideration. However, for higher temperatures, consideration should be given to a design which reduces temperatures in this area. In the case of large circular frames, a common method for hot to cold designs utilises a stepped flange as shown in Fig 9. This design provides a greater degree of structural flexibility in the hot flange side, reducing distortion yet allowing significant temperature reduction between the inside frame and the outer, bellows clamping area.

FIG 9



4.2.4. High Ambient Temperatures (Restricted Ventilation)

Standard fabric expansion joints are designed to withstand the full gas temperature, but for them to achieve this there must be a relatively cool ambient temperature of less than 60°C. Their own internal insulation is designed to reduce operating temperatures sufficiently for the gas barriers to operate within design limits.

Ambient temperatures greater than 60°C can occur when joints are fitted within acoustic enclosures or the outer surfaces of the joint are in close proximity to a wall/ceiling etc. This can result in overheated expansion joints and subsequent premature failure. Design of the expansion joint in these cases is therefore critical. Metallic foils can be used for higher temperatures, but their tolerance of axial and lateral movements is limited. The solution relies predominantly on providing additional cooling on the outside of the joint, to remove heat.

4.3 Water washing

Expansion joints are designed to withstand hot gases and thermal movements, but not fluid build up from water washing of the duct work or turbine. There are several consequences to water washing. Firstly, water has a corrosive effect on insulation materials, reducing their strength and joint integrity. Secondly, solvents in the cleaning fluids can be deposited within the insulation, damaging the joint and causing a potential fire risk. There are some materials that can help prevent the permeation of fluids but these will not completely eradicate the problem. Mechanical design adjacent to the joint also needs to be considered to eliminate contamination of the expansion joint materials. (See Fig 10).

FIG 10
Water washing

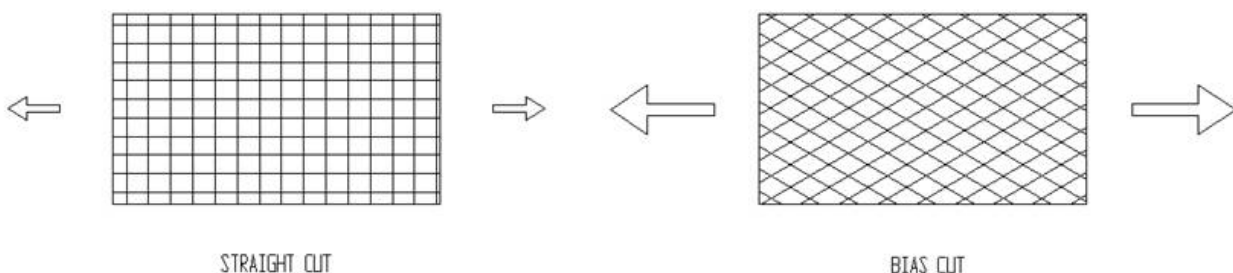


4.4 Radial Growth

There are many factors to consider when selecting materials, configurations and methods of manufacture for an expansion joint. Heating of the mounting frames during operation results in radial growth; typically a 5m square duct may grow to 5.05m square at 550°C.

Expansion joint materials have differing coefficient of expansion values to that of their metal frame counterparts and so considerable stress can be induced into the materials if the design does not cater for this. Reputable suppliers are aware of this problem and utilise bias cut materials in the construction, enabling the stress to be eliminated. (See Fig 11).

FIG 11



4.5. Insulation Bolsters/Pillows

4.5.1 Pillow Loss

The velocity of gas turbine exhaust gases is high and can cause negative pressures and turbulence in the area of the expansion joint. This can result in a drawing or sucking effect on the bolster/pillow materials creating a “picking effect”, which picks at the individual fibres of the insulation material and gradually destroys the integrity of the bolster/pillow unit. This tendency accelerates over time.

It is not unknown for the entire pillow/bolster to be sucked downstream of the joint position. To prevent this, the bolster should be pinned to the frames or attached at the flanges. Whilst this prevents total bolster/pillow loss it will not prevent the “picking” effect. When fitting, care should be taken to ensure that the thermal movements can be accommodated. The “picking” effect can be controlled by the use of correctly chosen internal meshes of fine wire or, if practical, the use of a floating internal second sleeve. (See Fig 12).

FIG 12
Floating sleeve



4.5.2 Pillow/Bolster Settlement

Insulation is produced from a combination of woven fabric materials and felts (glass, basalt and or ceramic). Whilst these materials have densities in the order of 100 to 150 kg/m³, they are none the less quite weak. There is a risk that the vertical sides of expansion joints can suffer, destroying themselves under their own weight, settling to the bottom of the vertical leg and exposing the top corners.

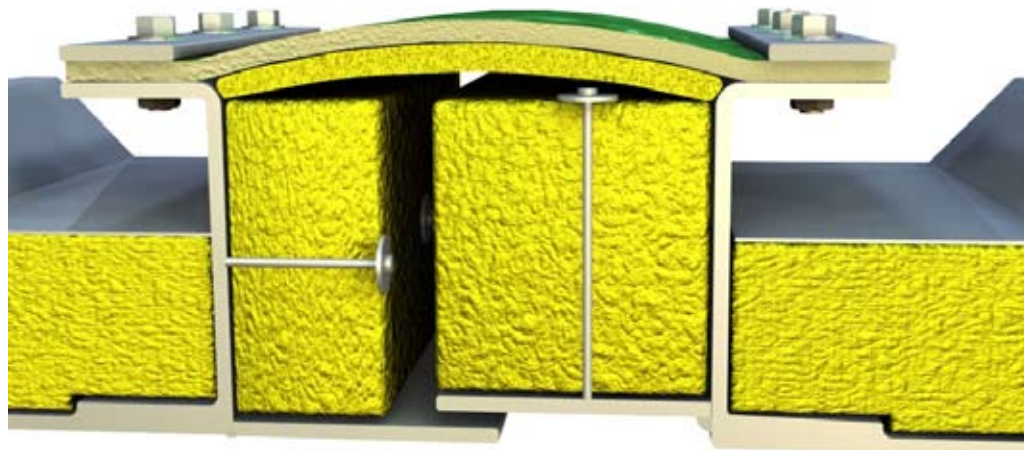
Pillows/bolsters should therefore be manufactured using quilting pins equi-spaced throughout the width and length in order to maintain integrity during installation and operation. (See Fig 13)

FIG 13



In addition the bolster/pillow should be pinned to either the side walls of the frame or flow sleeve to secure and prevent slippage. (See Fig 14).

FIG 14
Quilted bolster and pinned to flow sleeve



4.5.3 Bolster/Pillow Permanent Set

Another of the bolster problems, which occurs during extreme movement, is the permanent compressive set of the insulation materials. This can result in migration of the materials from the upstand of the Expansion Joint mounting frames and consequential hot gas leakage directly to the clamping area with over heating of the expansion joint.

This can be overcome by recent developments including the split bolster principle as shown in Fig 14. The two bolster sections are each fixed to their adjacent support frame to prevent the problem occurring. The initial gap in the centre in the cold condition progressively closes during warm up and seals at full operating temperature with a slight interference or “nip”. This is perfectly acceptable as there is no direct gas impingement on surfaces, which could affect the expansion joint materials. (See Fig 14)

4.6 External Insulation

Expansion joint manufacturers insist that the outside of gas turbine expansion joints must NOT have insulation placed over them. As described previously, covering the joint would result in the gas barrier materials being subject to high temperatures and cause premature failure. The external insulation should be terminated as shown in Fig 8. Failure to do this could jeopardise any FEA calculations applicable to the design file or cause premature failure of the expansion joint.

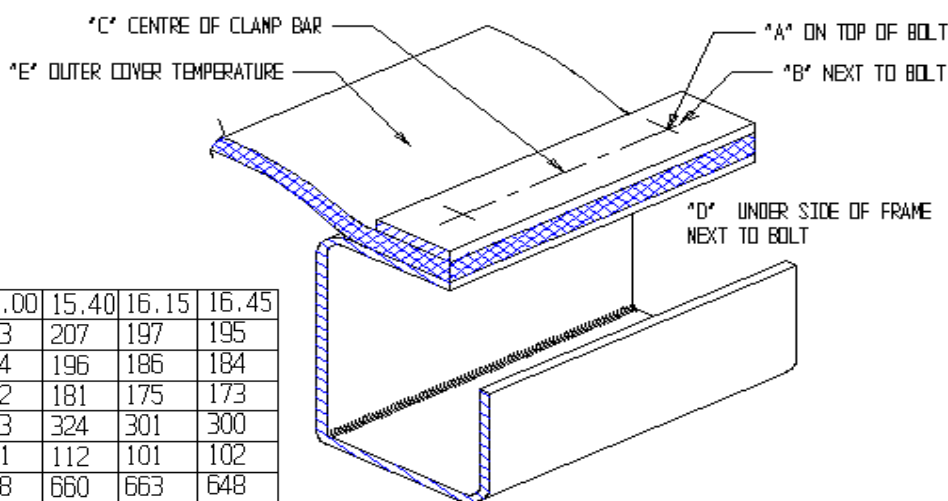
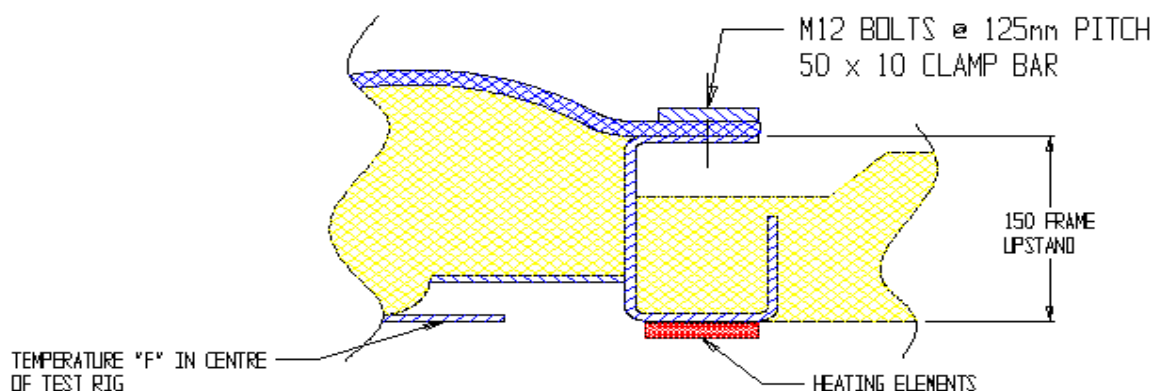
4.7 Noise

Noise requirements must be specified at the enquiry stage as they can significantly affect the design of both the fabric element and steel work. To achieve optimum noise reduction, it is necessary to use the highest density materials that will operate at the design parameters. The internal flow plates should be designed to reduce any gaps and a floating sleeve may be the best option.

4.8 Frame Temperatures and Personnel Protection

James Walker Townson has carried out exhaustive test work in the laboratory in order to determine anticipated temperatures throughout the expansion joint frames. Early frame designs would have a typical temperature profile as shown in the sketch below.

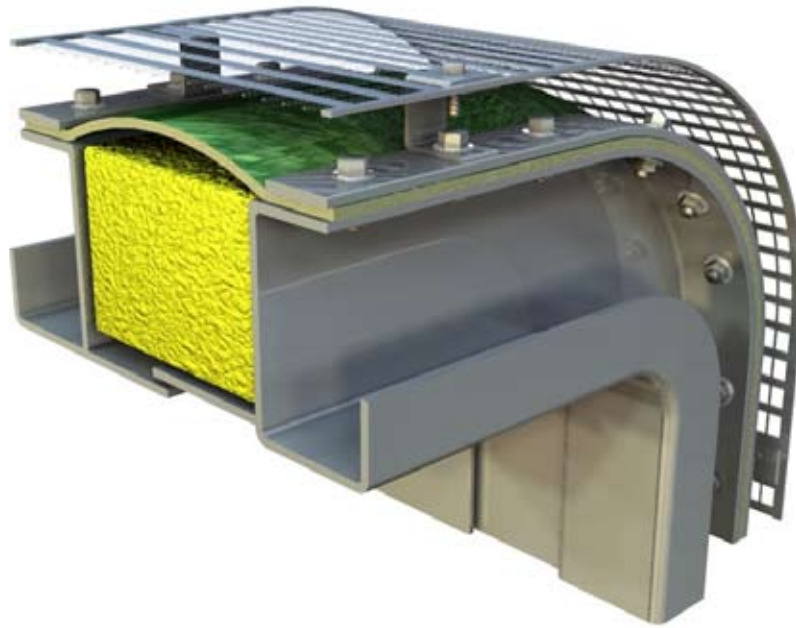
FIG 15



TIME	12.45	14.00	14.40	15.00	15.40	16.15	16.45
A	122	174	187	193	207	197	195
B	114	170	179	174	196	186	184
C	108	153	166	162	181	175	173
D	190	249	286	303	324	301	300
E	72	96	99	101	112	101	102
F	-	490	541	608	660	663	648
G	450	500	550	600	650	650	650
NOTE : "G" IS THE HEAT CONTROL SETTING							

From these simple test results it can be seen that the external temperature of clamp bars and bolts can be sufficient to cause burns and often some form of protection is required. This should take the form of a mesh guard over the outside, providing protection to the individual but also permitting good air circulation to allow cooling of the expansion joint. (See Fig 16)

FIG 16



4.9 Routine Maintenance

- Considered to be a wearing part.
- Need to be replaced periodically.
- Avoids costly shut downs.
- Does not require actual maintenance.
- Should be regularly checked. (see below)
- Ensure Joints are kept clean and free from debris.
- Dust that gathers on top of the joint is effectively reducing the life of the joint.
- Do not allow items to be stored on the joint or rested against the side. (particularly scaffold items)
- Ensure bolts remain tight, as originally specified by the supplier. Periodically they may require checking or re –tightening.

4.10 Inspection

- The most basic form of inspection is visual. Periodically check the joint for any whitening. This is a sign that the joint is under thermal stress.
- Elastomeric joints deteriorate differently. Chemical attack starts on the inside surface and can appear as a granular ball in the early stages, developing into de-lamination. Chemical attack can also appear as a paste or sticky substance on the surfaces.
- Monitor the progress of any whitening as in some cases it could spread quickly. There are no hard and fast rules as to how long the joint will last after degradation starts.
- Thermal monitoring is a positive and preventative approach as any heat build up will be detected early. Temperatures reaching 200°C on the outer surface of the joint require some attention.
- Thermo- graphic surveying is the most effective approach to monitoring and James Walker Townson are able to provide such a service and report by providing a documented health check on the expansion joints within a system.

5. CONCLUSION

Non-metallic expansion joints will provide years of trouble free service if designed and installed correctly. One of the most common reasons for expansion joint failure is incorrect installation or damage during installation. Emphasis must be placed on strict adherence to the guidelines laid down in the installation manual that is supplied with the joints. These instructions have been developed over many years of experience of fitting joints and solving problems. To ignore or deviate from them is risking joint failure.

In conclusion, non-metallic joints are the most cost-effective method of accommodating thermal movements in gas turbine and HRSG applications. To provide a safe, quality, long-life solution however the expansion joint supplier must have a proven track record over many years of manufacture and on-site installation experience combined with modern technological tools, such as FEA, that are necessary for the analysis and design of the system.



James Walker Townson is one of Europe's leading specialists in the design, manufacture and installation of flexible expansion joints and bellows.

The company is a member of the European Sealing Association and reference lists of installed applications highlighting the company's experience with the most difficult applications are available on request.

James Walker Group

The James Walker Group — of which James Walker Townson is a member — is a global manufacturing group. It has over 50 production, engineering, distribution and customer support sites across Europe, Australasia, Asia Pacific, Africa and the Americas. The close-knit network of Group companies and official distributors provides products and services to customers in well over 100 countries.

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