COLD SPRING OF RESTRAINED PIPING SYSTEM

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ABSTRACT

Power piping is often installed with cold spring to control the initial hot reaction and to protect the connected equipment. However, cold springing of a restrained or a branched system is a very sophisticated procedure which can lead to an unpredictable result if it is not done properly. This paper discusses the procedure and the problem associated with the cold spring process. It also presents the method adopted by computer programs in analyzing the cold spring effect and in preparing the cold spring data.

INTRODUCTION

Cold spring, prespring, and cold pull are all referring to the process which stresses the piping at the installed or cold condition in order to reduce the stress at the operating or hot condition. The process involves laying out the piping somewhat shorter than the installing space. This creates a gap at the final weld location when the system is erected. The system is then pulled or pushed according to a predetermined procedure to close the gap and to finish the final weld. The gap is sized depending on the cold spring factor desired. A 100 percent cold sprung system will have the gap size equal to the amount of the system expansion minus the differential anchor movements. By the same token, in a 50 percent cold sprung system the gap size is set to one half of the system expansion minus the differential anchor movements. A 100 percent cold sprung system, if installed properly, will have the expansion stress reduced to zero when the system reaches the operating temperature. It will be free of any thermal expansion stress under the hot operating condition.

Cold spring is often applied to a piping system to, 1) reduce the hot stress to mitigate the creep damage, 2) reduce the initial hot reaction force on connecting equipment, and 3) control the movement space. However, at the creep range the stress will be relaxated to the relaxation limit even if the pipe is not cold sprung. The general belief is that the additional creep damage caused by the initial thermal expansion stress is insignificant if the total expansion stress range is checked within the allowable limit. The real gain of the cold spring has become the reduction of the hot reaction. The control of the movement space is secondary.

The general philosophy and the Code rules of the cold spring have been discussed by many writers [1, 2, 3, 4]. The detailed cold spring procedure has also been discussed fully [5, 6, 7, 8] in one of the special sessions given in the 1981 ASME Pressure Vessel and Piping Conference. This paper will focus on the discussion of the systems with intermediate restraints. Since the intermediate restraints are used for different purposes, each different system may have to have a different approach in cold springing.

LOCALIZED COLD SPRING

Cold spring is used mostly to reduce the hot reaction. The Code [9] stipulates that the hot reaction can be calculated by Equation (1).

$$R_h = \left(1 - \frac{2}{3} C\right) \frac{E_h}{E_c} R \qquad (1)$$

Where, R_h = maximum reaction estimated to occur in the hot condition

C = cold spring factor varying from zero for no cold spring to 1.00 for 100% cold spring.

E_h = modulus of elasticity in the hot condition.

E_c = modulus of elasticity in the cold condition.

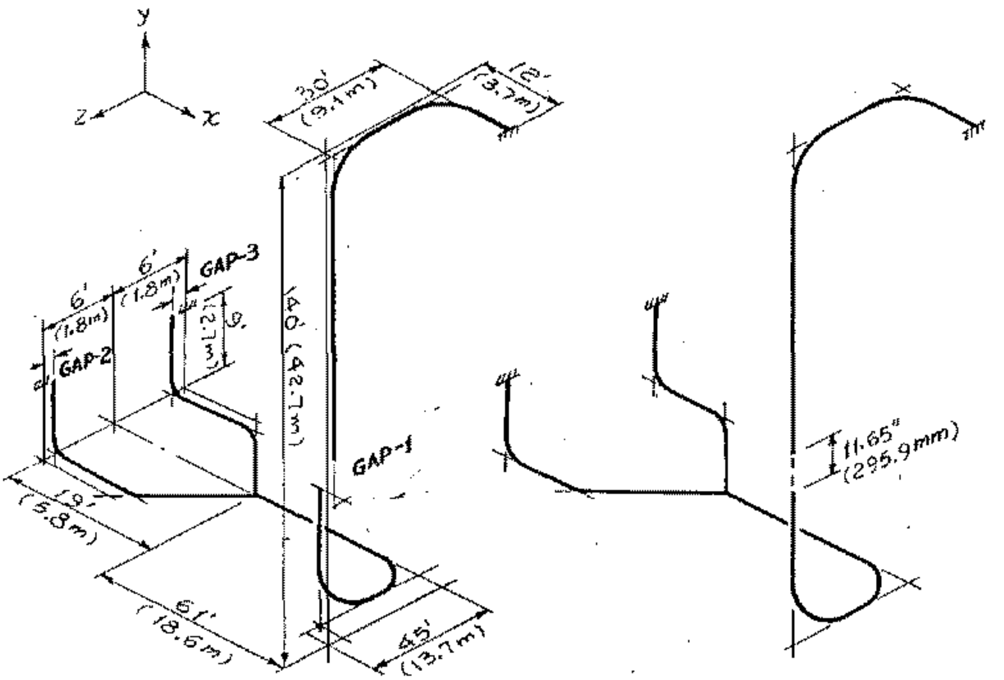
R = maximum reaction calculated for full expansion range based on cold modulus of elasticity and without considering the cold spring.

Equation (1) is applicable only when the entire system is cold sprung uniformly in all the directions. To achieve this uniformity, every leg of the piping has to be fabricated with cut short. Each branch of the system has to be erected with a cold spring gap as shown in Figure 1-(a). Although in most turbine connections the GAP-2 and GAP-3 are not required, in theory each branch has to have a cold spring gap so the system can be sprung uniformly.

As demonstrated in Figure 1-(a), in order to achieve the uniform cold spring the entire system is subject to the so called cold spring engineering. All the drawings have to be dual dimensioned with the design or spatial coordinates along with the cut shorts or erection coordinates. The expected cold spring movements also have to be specified in the same drawing or on another set of drawings. These all add up to the complexity of the design and the cost of the plant. To simplify the procedure, a less elegant approach of springing only one certain direction may be adopted. This unidirectional local cold spring often achieves the same effectiveness as the uniform cold spring, but at a much reduced cost.

In the system shown in Figure 1-(a), the spatial dimensions between the two fixed end points are: X=92' (28m), Y=131' (40m), and Z=15' (4.6m). From the basic beam theory it can be easily shown that at a given displacement or expansion, the displacement stress produced in the pipe is roughly inversely proportional to the square of the length. Furthermore, the displacement imposed on a given leg is proportional to the length of the lateral leg. By combining the above, it is clear that the stress produced by each leg is proportional to the cube of the length of the leg. In the piping system shown, although the Y-leg is only about 42 percent longer than the X-leg, the stress created by the Y-leg is about three times of the stress created by the X-leg. Therefore by 100 percent cold springing only the Y-direction as shown in Figure 1-(b), the expected hot stress will be reduced to about one third of the design stress range.

PIPE : 24" Sch-120 (610mm O.D., 46mm Thick)
ASTM A213, T11 (1-1/4 Cr - 1/2 Mo)
1000° F (538° C)



Thermal Expansion Stress:
No Cold Spring (hot): 9715
Local Cold Spring (hot): 2016
Local Cold Spring (cold): 9236

(a) Uniform Cold Spring (b) Local Cold Spring

Figure 1, Cold Spring Gaps

The actual calculation shows that the stress will be reduced to about one fifth of the design stress range. This is approaching the expected reduction from the uniform cold spring in view of the fact that the uniform cold spring is much more difficult to accomplish.

By comparing both Figures 1-(a) and 1-(b), it is apparent that the dual dimensional drawing is not needed for the unidirectional local cold spring. The ordinary layout drawing can be used with little modification. The only additional dimension required is the gap location and the gap size. It should be noted that the gap location shown may not be the best location available. It is only used to demonstrate the simplicity of the method.

COLD SPRING PRACTICE

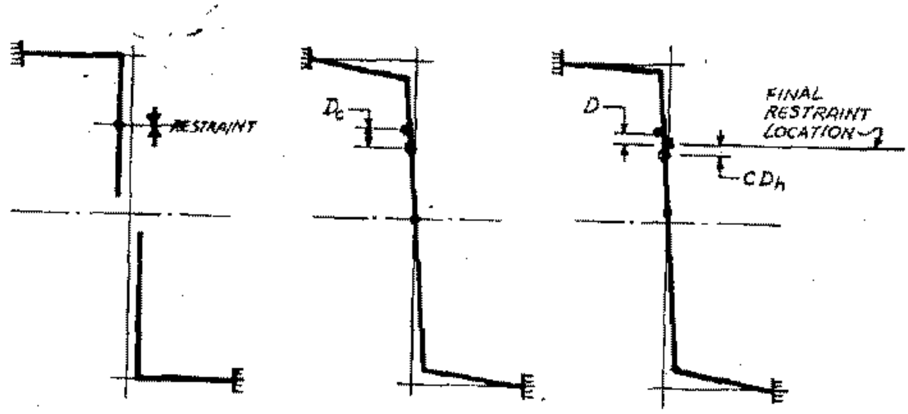
Cold springing is beneficial in reducing the hot reaction and in assisting a system to reach the relaxed stage quicker. When a system reaches the relaxed stage quicker, it mitigates the creep damage caused by the hot stress during the initial operation period. Though with all these benefits, the practice of cold spring varies from industry to industry. In the fossil power industry, due to the turbine manufacturers' insistence and the industry's long time tradition, almost all the main steam and reheat steam pipings are cold sprung. This is mainly because these lines are always operating at the creep range and the cold spring has been recognized to be able to reduce the creep damage. Also because the cold spring is a rather expensive procedure, once the decision is made to spring it is generally set to achieve the maximum benefit from it. That is if the line is to be cold sprung, it is almost always done with 100 percent. Other lines are very seldom cold sprung due to the low operating temperature. Cold spring can be used at low temperature lines in reducing the hot reaction, but the benefit is not as great as in high temperature lines. The hot allowable reaction and the cold allowable reaction normally differ very little. This makes the shifting of the reaction from the hot condition to the cold condition not very attractive. In the nuclear power industry the piping is not cold sprung again because of its rather low operating temperature.

Engineers in the petrochemical industry are normally not very keen in cold springing, although many systems in the process plants operate in the creep range. This is partly due to practicality and partly due to the opinions of their pioneers [1, 2, 3]. The piping in a process plant is generally more complex than the piping in a power plant. Also the engineering and construction schedule is generally very short. This combination makes the cold spring very impractical. However, that does not mean that the process industry does not want to take the advantage of cold springing. It is just a matter of the cost effectiveness. The cost of the additional engineering and the extended construction schedule outweighs the limited reduction in creep damage at the initial operating period. Cold spring is occasionally used to reduce the equipment load in a process plant, but that is only limited to localized springing. The cold spring factor in this case seldom exceeds 50 percent. It should also be noted that normally special approval is required to perform a cold spring in a process piping. There are a lot of places where cold spring is not allowed. These are at the areas where cold spring is most logically needed. For instance, one of the most difficult piping to design is the compressor piping which has to meet the very low allowable nozzle load imposed by the manufacturer. If cold spring can be applied judiciously, the load would be easier to meet. But cold springing on those pipings is generally not allowed. One of the reasons which prohibits the cold spring is the low operating temperature involved in those pipings. The theoretical cold spring gap and the springing movement involved are all very small. Since it is very difficult to measure and control these small displacements up in the air in the field, the effectiveness of the cold spring is unpredictable. It might even produce a load which is damagingly high to the equipment. In any case if a cold spring is desired, then a special procedure has to be invoked to ensure the intended result.

ANALYTICAL PROCEDURE

With the advantage of the computer technology nowaday almost all the pipe stress calculations are done by digital computers. Therefore, it is important to see how a computer program is implemented to analyze the cold spring effect. In a modern pipe stress computer program the cold spring is analyzed by the combination of the cold spring gap element and the support displacement. Of course, if the cold spring is uniform, the system can be analyzed by adjusting the expansion rate to match the cold spring factor desired. However, by adjusting only the expansion rate will not be enough to produce the data needed for cold springing a system with intermediate restraints.

The cold spring gap element is used to pull both ends of the gap together. If the gap element is used at the operating temperature, the analysis simulates the hot condition. On the other hand if the gap element is used with the ambient temperature, then the analysis simulates the theoretical cold springing process giving the pipe forces, displacements, and stresses of the system after the pull. However, if the system has a rigid intermediate restraint as shown in Figure 2, the analysis is somewhat more complicated. Since the computer program cannot automatically compensate for the restraint movement adjusted during the cold springing, the analysis actually considers the restraint as fixed before the cold springing. This of course does not represent the actual case when the restraint is continuously adjusted during the springing. Therefore, a valid analysis will need the input of the restraint movement in addition to the cold spring gap. The movement of the restraint can be calculated as in Equation (2).



(a) Erected Position (b) Gap Closed (c) Restraint Installed

Figure 2. Restraints Installed after Cold Spring

$$D = D_c + CD_h \quad (2)$$

Where, D = restraint displacement adjusted during the cold springing.
D_c = cold spring displacement without including the restraint.
C = cold spring factor
D_h = hot displacement without considering the gap and the restraint.

The displacements given in Equation (2) are all in reference to the erected position just before the springing. Equation (2) can be obtained by performing two analyses. One for D_c and the other for D_h. It can also be achieved by a single combined analysis using an expansion rate equals to the actual expansion rate modified with the cold spring factor, combined with the cold spring gap. The final stress analysis is done with three different computer runs. The Code stress compliance check is performed without considering the cold spring. The Code does not give the cold spring any credit in reducing the the stress. The hot reaction is calculated by using 2/3 of the design cold spring gap plus 2/3 of the restraint displacement as calculated in Equation (2). The Code only gives 2/3 of the credit in calculating the hot reaction. Finally, the cold reaction is calculated by using the ambient temperature plus the full cold spring gap plus the full restraint displacement. The cold reaction caused by the self springing due to the stress relaxation also needs to be checked using the formula given in the Code [9].

RESTRAINT INSTALLATION

Restraints are used for: 1) supporting the weight, 2) resisting occasional loads such as earthquake and steam hammer, and 3) controlling the pipe force to protect sensitive equipment. In each application a specific way of cold spring procedure is normally called for.

In a cold sprung system, the weight is normally supported by spring and constant supports to reduce the expansion stress. However, at places where the expected thermal displacement or the expected restraint force is small, the rigid supports are used to reduce the plant cost and also to help stabilize the system. Rigid supports also serve to resist the occasional load. Since rigid supports are normally those of adjustable type, they are used to support the weight as usual during the cold springing. The support points are adjusted constantly throughout the cold springing process. The final location are set to the values as calculated in Equation (2).

In addition to supporting the pipe weight, restraints are often required in resisting occasional loads Restraints which are designed solely for the occasional load can be installed after the cold springing is completed. For instance, in a uniform 100 percent cold sprung system the restraints can be installed when the system is hot at the operating temperature Since the stresses and the restraint forces are zero at hot condition, the restraints can be installed very easily without any springing. The force and stress at cold condition can be calculated either by using a negative expansion rate (contraction rate) or by simply reversing the quantities calculated with the operating temperature without cold spring gap. In either case the restraints have to be included with no displacements.

For systems which are designed for non-uniform cold spring or for less than 100 percent cold spring the restraints are normally installed right after the cold springing at the cold condition. The restraints are then adjusted to move an amount which is given in Equation (2). The support adjustment displacement given by Equation (2) is to be done in reference to the erected position before springing. If the reference is to be taken based on the cold sprung position before any restraint is installed, then the adjustment displacement CD_h should be used. It should be noted, however, that once the system is pulled by any one of the restraints the entire system position will be shifted from the original cold sprung position. The reference points will be changed due to this shifting. It appears that it is easier to use the erected position as the reference. Because the erected position is either the same as or in parallel to the design spatial position.

Another category of restraints are those used in the protection of the sensitive equipment. Most pipe stress engineers know that the most difficult part of pipe stress analysis is to meet the allowable loads given by the vendors of the rotating and other types of sensitive equipment. To meet the allowable, an ingenious layout coupled with strategically located restraints are generally called for as shown in Figure 3. Occasionally a localized cold spring is also applied to split the expansion force into, cold and hot, two parts. In this case, the restraints have to be installed before the cold springing. Otherwise, the cold load due to cold spring would be too much in most of the systems. This is due to the fact that without the restraints the load acting on the machine can be as high as one order of magnitude over the load of the restraint protected system. The cold spring factor used under this type of application is normally set at 50 percent. The maximum value used is 75 percent. With 75 percent cold spring, the hot and cold load can be calculated based on the code rule as in Equation (3).

$$R_h = [1.0 - 0.75\,(2/3)]\ R = 0.5\,R \qquad (3)$$

$$R_c = 0.75\,R$$

Since most of the vendors will allow 50 percent more load when the machine is idle, the above hot and cold loads have the same equal significance. The cold spring in effect reduces the piping load by 50 percent in relation to the equipment allowable.

The calculation in this situation is very straight forward. The cold load and stress are calculated by including both the gap and the restraint, at ambient pipe temperature. The theoretical hot load and stress are calculated again by including both the gap and the restraint, but at the design pipe temperature. In this application, since the support is stationary during the cold springing, no support displacement needs to be included. As the Code only allows 2/3 of the cold spring credit, the gap should be reduced by 2/3 before being used in the hot load calculation.

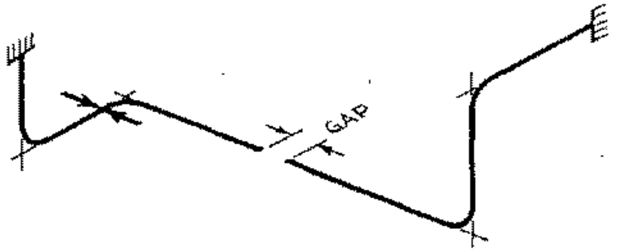


Figure 3, Restraints Installed before Cold Spring

CONCLUSIONS

Although the Code [9] does not allow any cold spring credit in evaluating the thermal expansion stress, cold spring of a piping system has a definite benefit in mitigating the creep damage. Cold spring is a sophisticated process requiring well established design and installation procedure which can increase the plant cost and delay the construction schedule. Engineers should also be aware the fact that different industries have different cold spring practices. If a given industry is not prepared to do the cold spring for economic or other reasons, then it should be avoided.

With the analytical tools available today, the cold spring effect can be analyzed as easily on nonuniform cold spring as on uniform cold spring. In view of the complexity associated with the uniform cold spring, now may be the time to start thinking about the non-uniform springing. A localized unidirectional cold spring, which is much simpler to apply, can be used to achieve the same effectiveness as the uniform cold spring in many cases.

Intermediate restraints are used in piping system to: 1) support the weight, 2) resist occasional load, and 3) protect equipment. Each application has its own cold spring procedure. The weight support is normally installed before the cold springing with the support element constantly adjusted throughout the springing process. The restraints designed solely for resisting occasional load are normally installed after the cold spring is completed. If the system is 100 percent uniformly cold sprung, then these restraints can be installed when the system is hot. This avoids the springing of the restraint element. If the system is not 100 percent uniform sprung, then restraints are installed at cold condition with a displacement applied to achieve the required springing. For those restraints used in protecting sensitive equipment, they are installed before the cold springing, and are fixed in place from the very beginning. Because of these different procedures, the analysis method is also different for each application.

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