Technical Report on Capabilities of API Integral Flanges Under Combination of Loading—Phase II

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1 Scope

The evaluation of the load carrying capacity of API 6A integral flanges is the objective of this work. The applied loading includes the end tension and bending moment in addition to the conventional rated pressure and makeup forces. The effect of a temperature difference corresponding to 250 °F on the inside and 30 °F on the outside was also evaluated.

Three-dimensional finite element meshes were generated for the Type 6B, and Type 6BX flanges. The bending moment load case required a model of one quarter of the flange which was built up from the smaller segments and the half-bolt superelements. The computer program SESAM was used to obtain the stresses at selected critical flange and hub sections and to determine the gasket reaction due to each of the four unit load cases and the temperature difference load case. Leakage criterion was defined as the load combination which reduces the initial makeup compressive forces in the gasket to zero. The stresses in each defined section were linearized in accordance with the ASME *Section VIII*, *Division 2*, procedure to determine the membrane and membrane-plus-bending stress intensities. These stress intensities were checked against the allowables specified in API 6A, and the limiting loads were determined. A computer program LCCP was written to carry out this code check and a LOTUS 1-2-3 Release 2 worksheet was used to plot the load combination charts.

The results of the analysis carried out indicate that the leakage criterion governs the capacity of the smaller flanges in the Type 6B flanges. Leakage was governing for up to 9 in. size flanges in both the 52.5 ksi and 40 ksi makeups for the 2000 psi pressure. Leakage was governing the 5 $^{1}/_{8}$ in. for the higher pressures. Leakage was also found to be governing all Type 6BX flanges for working pressures of up to 5,000 psi. For the 10,000 psi and 15,000 psi flanges, leakage governed only in the larger size range greater than 2 $^{9}/_{16}$ in. Leakage was governing in all the 20,000 psi API 6BX flanges. The leakage model adopted in this study employs several approximations that have not yet been evaluated. Therefore, the actual leakage forces, i.e. load combinations leading to leakage, may be considerably higher than assumed herein. In reality, the gasket only leaks when its energized capacity is exceeded.

The state of stress at the stress governing hub section under the combined loading of makeup, pressure, tension and bending moment is considered to be "secondary." However, when pressure, tension, and bending moments are applied together with the necessary makeup to resist these actions without leakage, the state of stress is rendered "primary" and, therefore, the allowable stress intensities are halved. This does not seem to be consistent, and it may by far exceed the intention of the code. However, the oversight subcommittee preferred to adopt the conservative route, which may be overly conservative pending further evaluation. Therefore, it may be concluded that when the hub stresses are treated as primary, most flanges do not possess significant reserve strength beyond the leakage condition. In fact, if the leakage condition was somewhat conservative, the stress condition may become governing for most flanges.

The temperature difference of 250 °F internal and 30 °F external leads to increases in the load-carrying capacity of the flanges. This condition is caused by the compressive forces generated in the gasket due to this temperature difference, and the increase in the allowable stresses when the self-limiting temperature load condition is included. It is recommended that a 3-D finite element, nonlinear material and geometric models of approximately eight flanges be carried out to determine the actual failure mechanism that governs the behavior of these flanges. This includes the prediction of the response of the gasket under increasing load and a more accurate definition of the leakage mechanism. The elimination of the raised face does not significantly reduce the stresses in the hub which caused six Type 6B flanges to fail to meet the ASME criterion for makeup load only (52.5 ksi for 105 ksi bolting). The stress intensities were reduced only by about 5 % when the raised face was eliminated, increasing the thickness of the flange by about 10 %. The hub thickness for these flanges had to be increased by up to about 27 % of their existing thicknesses together with the elimination of the raised face.

The bolt stresses did not govern for any of the flanges analyzed. Bolt stresses are typically within approximately 67 % of their yield strength due to makeup, pressure, tension, and bending moment loads. The bolts are expected to be made up to half their yield. The stresses in the bolts due to temperature differences increase by about 5 ksi to 7 ksi, which is about 6 % to 8 % of the bolt yield stress. The other load conditions (pressure, tension, and bending moments) increase bolt stress by twice the increase due to the temperature difference. Therefore, it is concluded that the bolts will not approach their limiting criterion under the investigated load conditions.

2 Introduction

The original design criteria, of which API flange dimensions are based, were developed in the late 1920s and 1930s by Waters prior to the advent of the recent powerful, computer technology and associated finite-element analysis programs. The original analysis methods were used successfully in defining the flange design and pressure rating but did not address external loading capabilities. The flange designs were based on surface stress calculations, which are appropriate for uniform-axis symmetric loading conditions as used for bolt loading and pressure. Determining the limiting conditions of flanges beyond that of pressure rating, where external loading is considered, requires knowledge of stresses as they are distributed through the thickness. Methods of calculating these stresses have been developed through the use of finite element programs, and have been applied in this technical report.

The criteria for design stress allowables of API 6A body, bonnet, inlet and outlet connections were established in the Fifteenth Edition. Conformance with the API 6A criteria requires stress linearization calculations based on the methodology established by ASME *Pressure Vessel Code*, *Section VIII*, *Division 2*. These stress allowables are defined in terms of stress distributions through the thickness and necessitate a more accurate means of calculating component stresses as provided by finite element analysis.

Therefore, it was the intent of PRAC 86-21 (API 6AF) and the present work to establish a better understanding of the stress distribution in these flanges under the effect of the combined actions of pressure, bending moment, tension, and the original bolt makeup of the flange. Thus, the flange capacities which meet the design stress allowables of API 6A are determined.

The pressure/bending moment/tension charts developed in this technical report provide the critical load combination limits for either ASME/API 6A stress criteria or to leakage. These charts are extremely useful for both designers and users of API flange connections where external load capacities are critical.

The results of the work conducted in this technical report indicate increased load-carrying capacity for several flanges based on separate stress-limiting criteria. These stress limiting charts were not provided separately in the original work of API 6AF, which combined them with leakage criteria. The three-dimensional model analyses of this study provide verification that axisymmetric finite elements results of flanges, as used in API 6AF, are conservative. Additionally, this study determined a few flanges to have less loading capacity than originally defined in API 6A for makeup loading, and thus, have been reduced to meet design requirements.

The specifications for flange designs of Type 6B and Type 6BX originated in API 6A but have extensive diversification into other areas, such as surface and subsea drilling equipment and subsea production equipment. The API specifications for these applications either duplicate the design or reference back to the API 6A document. Therefore, use of the charts provided within this technical report have a broad base application where external loading conditions are critical.

It should be noted that the work presented herein has several limitations due to the defined scope and the assumptions involved in the analysis: the effects of transverse shear and/or torsion were not considered; the results are for static loading only, no dynamic, fatigue, or fretting phenomenon were accounted for; no elevated temperature effects were considered in the thermal stress analysis performed, only steady-state heat conduction was applied; the results representing the onset of leakage are based on linear behavior assumptions and are therefore only applicable to the linear range of the gasket response; and the load-combination capacity charts given are not intended to replace critical evaluation of any particular connection in an application where the charts show the flange to be marginal. These charts are intended to be used only as general guidelines for design.

Subsequent to the completion of this work, the $5^{1}/_{8}$ in. 15,000 psi flange was added to API 6A. This new flange was analyzed using the same basic methodology but with the ABAQUS general-purpose finite-element system, and using a