5. BOLTED JOINTS WITH FULL FACE GASKETS

5.1 INTRODUCTION

In the preceding two chapters, several topics concerned with flanges have been discussed. The previous analyses have considered the gasket as a lineal element located at a particular radial position. For the most part, the effect of non-linear gasket material behavior has been neglected in all previous analyses. This chapter focuses on development of an analysis method which can be applied to flanges with either full face gaskets or ring type gaskets. The proposed method also permits inclusion of non-linear gasket material behavior. The procedure assumes use of a computer to effect the solution; as such, the method may not be directly suitable for inclusion in any design code that is intended to supply simple formulas for the designer's use. However, we will show that it certainly has value as a design tool.

We have already noted that proper design of a flanged joint is not complete unless both structural integrity and joint leak tightness are assured. Most analyses used in practice tend to emphasize structural integrity (joint components are designed to experience preload and service stress levels below some specified value). It is generally inferred that maintenance of some preset stress level assures a leak-tight joint; however, there is no guaranteed relationship between flange stress level, bolt preload, and leak tightness since gasket material characteristics have an important effect. For example, we can demonstrate that a correct characterization of gasket material behavior is essential to the correct characterization of a bolted joint having full face gaskets.

In the previous chapter, the complete analysis of a circular flange with ring gasket-tubesheet-bolted joint connection was considered and we demonstrated how to predict service stresses in the various components as well as to predict deformations and residual pressure in the gasket region. A simplified ring type gasket model was adopted which modeled the gasket as a piecewise linear elastic spring with different spring rates for loading and unloading. We also assumed that the ring type gasket pressure force acted at a known, constant location on the flange.

This chapter focuses on a bolted flange joint sealed by either a full face gasket or a ring type gasket having a general non-linear loading and unloading behavior. We note that full face gaskets find their application in large, low pressure units with one of the most widely used applications in the rectangular shaped water box-tubesheet-condenser connection in power plants. A theory is developed for a three element joint connection having
two flanges and a spacer, together with a bolt and two gaskets with nonlinear material behavior. Figure 5.1.1 shows the typical configuration studied; the bolted joint is sealed by full face gaskets having nonlinear material characteristics.

5.2 GENERAL EQUATIONS

In this section, we focus on the general analysis and algebra necessary to develop an approximate method of analyzing the joints in question. We discuss configurations of circular plan form common to large commercial heat exchangers; the formulation is, however, directly applicable to power plant condenser configurations of rectangular plan form. Figure 5.2.1 shows the overall geometry of one of the elements between two bolt locations. The flange section is assumed to be an annular section extending over the radial region $-a \leq x \leq b$.

Loading and geometric symmetry permits focusing only on the portion of the joint between two bolt holes. The gasket between any two elements is a thin nonlinear elastic layer; for the purposes of this simulation the gaskets are modelled as discrete springs with strain dependent spring rates. For full face gaskets, the discrete non-linear springs are positioned at known locations within the annular plate segment; for ring type gaskets, the discrete non-linear springs are concentrated near the desired radial location. The springs are positioned radially to model the compression behavior of a specified area of the gaskets between two bolt holes.

Because of the non-linear character of the gaskets, an incremental formulation for simulation of loading and unloading is suggested. In the following description, certain approximations to reduce algebraic complexity are introduced:

1. Circumferential variations of flange displacement and loading between bolt holes are neglected.
2. Only large diameter flanges are modelled such that $a + b << R_b$. $R_b$ is the bolt circle radius.
3. The flange is modelled using ring theory.
4. In-plane (radial) movements are neglected.

The foregoing assumptions provide sufficient accuracy for design work; they may easily be lifted at the expense of formulation and computational complexity.

The complication in analyzing flanged joints accounting for a finite width gasket (having width comparable to the flange radial width $L$) stems from the non-linear loading, unloading, and reloading characteristics of the gasket material. When such a joint is pressurized, the separation and rotation of the flange rings produces wide variation in the distribution of the gasket surface pressure in the radial direction. Indeed, as the joint internal pressure is increased, one portion of the gasket may be loading (rising surface pressure) while another portion is unloading. The loading and