Advances in Bolting Technology

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ABSTRACT

A number of analytical and experimental programs have been launched to try to identify the causes and cures of bolted joint problems. This paper describes four such efforts; an extensive study of gaskets and leaks; an emerging ultrasonic technique to measure bolt tension, the early work of a new ASME Nuclear Power Codes and Standards Task Group to define good bolting practices; and a video cassette training program for bolting mechanics and engineers.

1.0 A PROGRAM TO STUDY THE BEHAVIOR OF PRESSURE BOUNDARY JOINTS

1.1 Early History

For over ten years the Pressure Vessel Research Committee (PVRC) has sponsored studies to define more accurate gasket factors (m and y factors). These factors have a strong influence on flange design, yet experiments by a variety of workers have challenged them; often suggesting new values which were several times the original values.[1]

1.2 Gasket Tests

Starting in 1974 a relatively short series of "Exploratory" tests were conducted and were reported by H.D. Raut and George Leon.[2] The tests showed that when you try to measure m and y by testing for leak rate you find that the results are affected by such things as the nature of the contained fluid, gasket width and thickness, contained pressure and assembly stress. Further, more detailed, work was then done to define in greater depth the basic behavior of the gasket and the contributions of the many variables involved. Early tests were conducted with a single test fluid on a single type of joint with a single style of gasket, and only at room temperature. Leak rates were measured, while gasket stress and contained pressure were varied. Gaskets were loaded,

unloaded, reloaded, etc. in a variety of sequences.[3] These tests were followed, from 1980 to the present, by Milestone and then "Production" Tests in which additional variables were involved; other gaskets, other test fluids, variations in flange surface finish, etc.[4]

1.3 A Simplified Gasket Test Procedure and Typical Results

Full details of the tests and their results can be found in the cited references. A summary of the final test procedure, and of typical test results, is given below. The test results reveal the basic behavior of a gasket. First, the procedure:

- 1.3.1 A small section of the gasket is subjected to mechanical tests to determine its basic force-deflection and creep characteristics.
- 1.3.2 A complete gasket is now subjected to a leak test in a raised faced flange of any convenient size. Tests will be conducted at room temperature, flange finish should be recorded. Any convenient test fluid such as helium can be used. The gasket is partially loaded and the leak rate is measured (at several contained pressures). The gasket is then further loaded and the leak rate again measured. Next, the gasket is partially unloaded and reloaded and the leak rate measured at various points. Additional load is placed on the gasket, a new and higher seating pressure, and the unloading-reloading tests repeated. After each increase in gasket stress the operator waits ten minutes before testing leak rate -- to accommodate gasket creep.

1.4 The Concept of Tightness

It was discovered during the program that the data for many tests could be combined if leak rates were defined by a dimensionless "tightness parameter" (T_p), which is defined in the references [4]. Briefly, if $T_p = 300$, it would take a contained pressure of 300 atmospheres to produce a "one unit leak rate" (1 mg/sec). This corresponds to a volumetric leak rate of about 7×10^{-3} pints per hour (3.6 ml/hr). Mass leak rate data is more informative than volumetric leak rates because the experiments have shown mass leakage to be approximately the same for all test fluids (liquids and gases) under the same test conditions (i.e., same gasket stress, contained pressure, etc.).[5]

1.5 Using Test Results

The test data allows us to characterize the behavior of a gasket in a variety of ways. Perhaps the most useful summary of the data is that shown in Figure 1. Let us assume that we initially load the gasket with a seating stress indicated by the point SA_1 on the curve. As we pressurize the system, reducing the stress on the gasket, its mechanical behavior will follow line U1. When gasket stress has fallen to a point defined by SG_1 on the graph, we will have reached the tightness parameter limit line. Any further reduction in gasket stress would result in a leak rate which exceeds the selected limit.

If, on the other hand, we initially seat the gasket to the stress indicated by the point SA_2 in the Figure, we can unload it all the way to point SG_2 , before reaching the same limit in leak rate. One set of y and m gasket factors can be derived from the gasket stresses corresponding to points SA_1 and SG_1 respectively; a second (and "better") set from SA_2 and SG_2 . Note that there is no such thing as a "correct" set of m and y factors for a given gasket. These factors, instead, are variables which depend upon the mechanical and sealing behavior of the gasket, upon each other, and upon our selection of an acceptable leak rate.

2.0 USING ULTRASONICS TO ENHANCE THE INTEGRITY OF CRITICAL BOLTED JOINTS

2.1 The Need

One of the limitations of bolted joint technology is our general lack of control over the residual tension produced in fasteners by present assembly tools and procedures. Improved control is possible with a new type of ultrasonic instrument which allows more accurate control during assembly, and also allows operators to monitor relaxation effects caused by tightening adjacent fasteners, or relaxation caused by thermal cycles, pressure cycles or other load effects.[6]

2.2 Principle of Operation

A transducer placed on one end of the bolt generates a brief burst of ultrasound which travels to the far end, echoes off that end, and returns to the transducer. The time required for the round-trip is measured very precisely. As the bolt is tightened, the round-trip transit time increases because the bolt stretches, increasing the path length, and the stress level in the bolt rises, decreasing the velocity of sound. The resulting change in transit time is fed to a microprocessor which interprets the change as a change in the tension within the bolt. In order to do this the computer must also be fed information about the acoustic properties of the bolt and about its

geometry.

2.3 Sources of Measurement Error

Because the method is completely independent of the friction between nut and bolt or between nut and workpiece, it avoids most of the uncertainties inherent in conventional torque and/or torque-turn control systems. Substantial uncertainties, however, still remain, introduced by bolt-to-bolt variation in such things as the acoustic properties of the bolt, the stress levels within that portion of the bolt which is enclosed by the nut, the stress within the bolt's head, and by other factors.[7] In spite of considerations such as these, the method can be used to control or measure bolt tension with accuracies exceeding those of all but the most sophisticated torque-turn systems.

2.4 Measures Residual Preload

One of the big attractions of the technology is the fact that it can be used to measure residual preloads in bolts at any time after they have originally been tightened -- if they were originally tightened under ultrasonic control. As an example of such use, Figure 2 shows the sequence of preloads obtained in a flange joint when it was tightened using torquing tools. Note that the preload scatter in individual bolts after the first pass is only $\pm 25\%$ but rises to $\pm 300\%$ at the end of a normal, three-pass, cross-bolting, torque procedure. Such variation is typical in pressure boundary joints tightened by conventional means (hydraulic tensioners or torque wrenches), and can be avoided if ultrasonics is used for control.

The accuracy with which the stress in a bolt can be measured ultrasonically depends upon the care which is taken to control or measure joint grip length, and bolt geometry, and to mount the transducers on the bolts. Residual preload accuracies of $\pm 1\%$ are possible but are expensive and time consuming. In most nuclear applications we are content to accept accuracies of $\pm 10\%$ residual preload, substantially better than the typical $\pm 300\%$ we saw a moment ago.

3.0 A NEW STANDARD FOR NUCLEAR BOLTING ACTIVITIES

As part of the overall effort to minimize future bolting problems, the Committee on Operations and Maintenance of the Nuclear Power Codes and Standards Committee of the ASME has recently established a Task Group to draft a new standard on bolting practices. The following is very preliminary, but the standard may cover such things as selection of

detailed assembly and disassembly procedures (torque, tension, stretch, etc.); selection of torques or other assembly specifications; when and how to modify procedures or specifications to respond to field problems, etc.

4.0 TRAINING PROGRAM ON THE MAINTENANCE OF PRESSURE BOUNDARY JOINTS

It will be some time before the programs described above will bear fruit. In the meantime, there is a strong desire to do a better job with the knowledge, tools and procedures available today. To this end a training program for bolting mechanics and their supervisors is being developed by EPRI and will be available in video cassette form by mid 1985.

REFERENCES

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FIG. 1 A line of equal tightness parameter ($T_p = 500$) superimposed on a stress-deflection curve of a spiral-wound gasket with asbestos substitute filling. This curve set defines the mechanical and leak behavior characteristics of this particular gasket in the region of interest. The gasket is originally loaded along curve A. It is unloaded and reloaded (e.g., by pressure cycles) along any of the curves labelled U.

FIG. 2 The preload created in 16 bolts in a 10" (254 mm) 600 lb. ANSI raised face flange, with a spiral-wound gasket, as the bolts are tightened in three passes. Bolts are numbered in the order tightened. Bolt #2 is located 180° away from #1 on the flange. Shown are the initial preloads in individual bolts on first tightening and the residual preloads in all bolts after the first and third complete passes (at different torques). Preloads were measured ultrasonically.