Experimental investigation on bolting assemblies submitted to cyclic loads

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1 INTRODUCTION

Design considerations may lead to the use of bolting or screwed connexions to join particular in sodium components of L.M.F.B. reactors. In these reactors, bolting connexions are to be chosen on criteria that may differ from those used in pressure vessel construction. For example in this case differential pressure is relatively low but thermal loads are cyclic and of large amplitude. Another particular problem is the often use of high strength materials for screws. These materials have higher elastic stress limit than strain hardening materials of the assembled components made often of austenitic steel. Because of thermal cycling the preload imposed during initial tightening can relaxe in some extent. Satisfactory operability of these components requires a minimal preload of the bolting connexion to be obtained during life time of the reactor.

An experimental investigation on a representative H.M.20 bolting assembly was performed to document this behavior and to verify the applicability of design rules available in construction codes like RCC-MR (1).

2 DESCRIPTION OF EXPERIMENTS

2.1 Experimental device

The principles of the experimental procedure consist of imposing cycling displacement to assembled pieces of a bolted or screwed assembly via a conventional testing machine. The tests are performed at room temperature.

The experimental device (see figure 1) is designed to permit direct measurement of preload and maintained load in the assembly. This load is present in the screw and is measured by the load cell of the testing machine.

Two particular parts are worth noticing in one experimental test specimen :

- the assembled drilled parts (superior and inferior) that are smooth or threaded,

- the screw or bolt.
The flanges, linked to machine arms, are designed to be rigid.

2.2 Specimens

A specimen consists of a M.20 assembly made of two different material parts (see figure 1 and table 1).

In this axisymetrical experimental arrangement the screws are in traction whereas assembled parts are in compression.

The bolts have a 120 mm long, threaded part.

The drilled pieces have an outside diameter of 100 mm, a thickness of 36 mm, a hole of Dp = 22 mm. When screwed connexion is concerned the threaded length is 24 mm.

Table 1. Material characteristics at room temperature.

Parts of specimen	Bolt	Assembled parts
Materials	Z6 NCT DV 25-15	316 L
E Young's Modulus (MPa)	186.10^3	191.10^3
R_e 0,2% (MPa)	450	245
R_m (MPa)	873	559

Four screwed specimens and four bolted specimens were tested in these experiments.

The imposed conditions are recalled in the Table 2.

The parameters significations are explained in the following paragraph.

Table 2. Experimental results

Test N°	Bolted	Screwed	dio mm 10^{-2}	Δdi mm 10^{-2}	P_o kN	P_{max} kN	Δε %	KS kN/mm	KG kN/mm	KA kN/mm
1	X		6.25	31.9	12.8	108		467	324	1058
2	X		12.5	25.4	32	100		443	326	1234
3	X		29.4	7.12	77.6	96		498	370	1439
4	X		39.3	18.2	95.2	32	0.16	445	345	1535
5		X	4.75	29.2	14.8	132		521	452	-
6		X	15.13	20.3	33.2	106		597	466	2123
7		X	19.3	5.62	79.2	100		604	483	2411
8		X	20.1	14.5	75.6	10	0.20	564	455	2354

2.3 Instrumentation

The following parameters are continuously recorded during the test:

- The strength, P, produced by the testing machine.
- The relative displacement, dS, between the head and the bottom of the screw.

- The displacement, di, taken "inside" the drilled pieces. This parameter controls the experiments (see figure 2).
- The displacement, de, taken "outside" the drilled pieces. The difference, di-de, is an evaluation of contraction of the two drilled pieces.
- The strain, ε, on the smooth part of the screw by the use of strain gauge on two specimens.

2.4 Loading

The displacement, di, controls (see figure 3):

- the preloading corresponding to a preselected value P_o by dio displacement,
- the cyclic under- or over-straining Δdi after 10 mn dwelling time. One hundred cycles are imposed.

3 RESULTS

3.1 Evolution of preload

A typical graphical recording of P maintained load versus di in a bolted assembly (test n°2) and a screwed one (test n°6) are presented in the figure 3. During production of preload P_o, the initial behavior is not at the beginning linear. A rather large di mini displacement value is necessary to permit relative positioning and alignment of different parts of the assembly. di mini is smaller for screwed assembly. When load is increased the curvature of the curve is inversed. Then P_o and the maximum force P_{max} are reached.

The dwelling times make negligible relaxation of load to occur in all experimental tests.

During first unloading and following cycles the relation between force and displacement is almost linear with a slope lower than the one reached at first loading for the same imposed displacement. It seems that elastic shake-down behavior is reached after the first cycle.

During the hundred of cycles performed the force value reduction is low. The load range ΔP for each cycle is practically constant.

3.2 Evolution of deformation in the screws

The deformation recorded on 2 specimens screws is constant in range during the test. Negligible cumulative deformation occurs in the very first cycles. The met rology of the screws before and after the test reveals no appreciable plastic deformation (even in the threaded parts).

The ranges of both screws deformation $\Delta\varepsilon$ are indicated in Table 2.

3.3 Evolution of displacement in the assembled pieces

For the displacement imposed, di, and because the recording of de is not taken close to the axis of asymmetry. These values are very small and present large dispersion.

4 DISCUSSION OF EXPERIMENTAL RESULTS

4.1 Evolution of rigidity in the bolted or screwed assembly

The linear elastic behavior described in § 3.1 is characterized by the variation of rigidity in the different parts of the bolted or screwed assembly. It is almost constant for one test specimen as far as cyclic straining produces no increase in maximal load P_{max}.

It is possible to characterize the rigidity of each parts of the assembly:

- the rigidity of screw by the equation:

$$K_S = \frac{\Delta P}{\Delta dS}$$

- the global rigidity of the bolted or screwed assembly:

$$K_G = \frac{\Delta P}{\Delta di}$$

- the rigidity of assembled pieces (because the recorded value de is not usable):

$$K_A = \frac{K_G \cdot K_S}{K_S + K_G}$$

The corresponding calculated values for the first unloading in each test are indicated in Table 2.

4.2 Non linear effects

Non linear relation between the force and the imposed displacement during loading is essentially first due to relative displacement and friction in the screwed or bolted assemblies. For higher values of loads, it seems also to be due to plasticity effects that are mainly concentrated in the assembled parts in contact with the screw head or bolt nut. These plastic deformations are evaluated correctly by the use of a rugosimeter.

5 SOME PRACTICAL CONCLUSIONS

5.1 Choice of preload

In order to reduce preload loss it is advisable to reach the maximal allowable load P_{max} in the assembly during the initial tightening. Then, the load must be reduced to a fixed preload value P_o lower than P_{max}, so that eventual ulterior over-straining do not make the load to exceed P_{max}.

5.2 Evaluation of rigidity

The construction code RCC-MR proposes practical rules to evaluate rigidity of screwed or bolted assembly parts from their geometrical dimensions (see figure 1) and elastic material characteristics (see Table 1).

For screwed assemblies:

. Screw rigidity: $K_S^* = \frac{\pi E}{4} \left[0.4d \left(\frac{1}{d^2} + \frac{1}{dn^2} \right) + \frac{\ell_1}{d^2} + \frac{\ell_n}{dn^2}\right]^{-1}$

$= 599$ kN/mm

. Assembled parts rigidity: $K_A^* = \frac{\pi E}{4L} \left[\left(a + \frac{L}{10}\right)^2 - Dp^2\right]$

$= 2098$ kN/mm

For bolted assemblies:

. Screw rigidity: $K_S^* = 446$ kN/mm (same formula)
. Assembled parts rigidity: $K_A^* = 1875$ kN/mm (same formula).

They agree fairly well with experimental calculated values presented in Table 2.

6 CONCLUSIONS

Eight ad hoc experimental tests on screwed and bolted assemblies made of stainless are performed under cyclic dilatations. The results permit to recommend a tightening procedure and to verify construction code rules given by the RCC-MR.

7 REFERENCES

(1) RCCM-MR. Recueil des règles de conception et de construction mécanique des ilôts nucléaires de la filière rapide. 1ère édition juin 1985. AFCEN. Diffusion par AFNOR. (English version available).

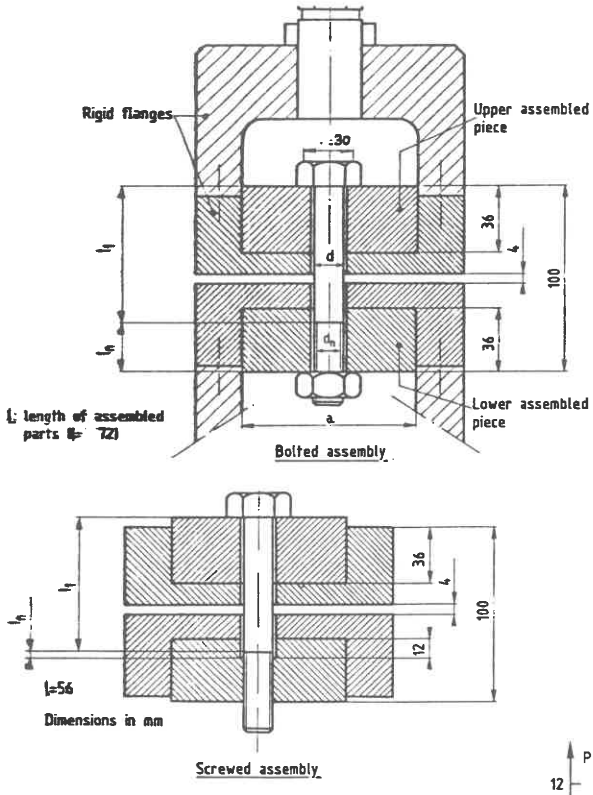

Fig. 1 - Experimental devices

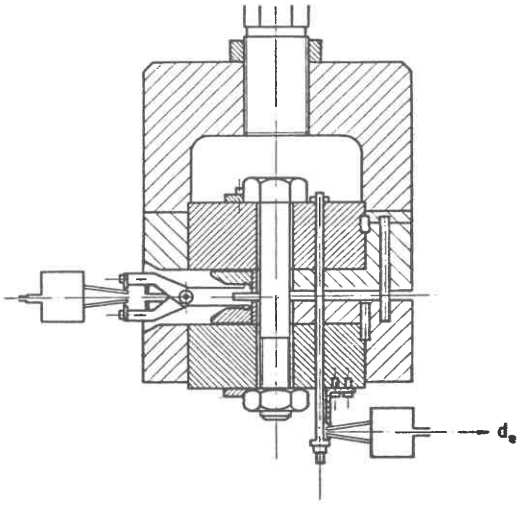

Fig. 2 - Instrumentation to record imposed displacement d_i and displacement d_e

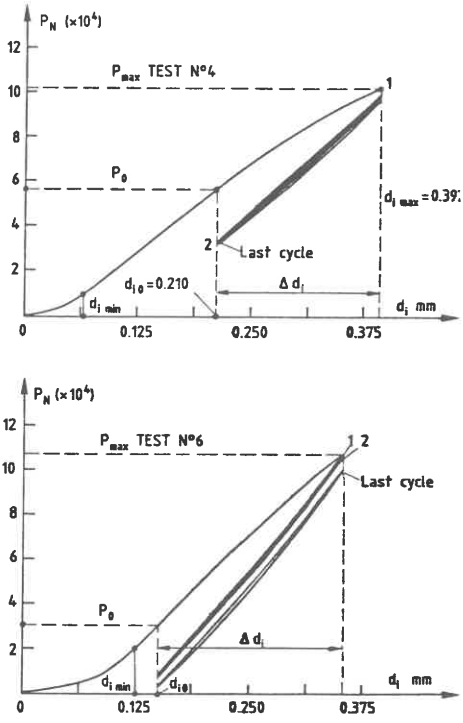

Fig. 3 - Typical recording of P versus d_i for 2 tests