A SIMPLE ARCHITECTURE FOR IN-PIPE INSPECTION ROBOTS

Mihaita HORODINCA, Ioan DOROFTEI, Emmanuel MIGNON, André PREUMONT

Active Structures Laboratory
UNIVERSITE LIBRE DE BRUXELLES
Av. F. D. Roosevelt 50, cp 165/42, Brussels, Belgium
Phone: (32)2-6504663 Fax: (32)2-6504660
e-mail: andre.preumont@ulb.ac.be

Abstract: The paper presents an original robot architecture for in-pipe inspection. The robot consists of two parts articulated with a universal joint. One part is guided along the pipe by a set of wheels moving parallel to the axis of the pipe, while the other part is forced to follow an helical motion thanks to tilted wheels rotating about the axis of the pipe. A single motor is placed between the two bodies to produce the motion. All the wheels are mounted on a suspension to accommodate for changing tube diameter and curves in the pipe. The robot is autonomous and carries its own batteries and radio link. Four different prototypes have been constructed for pipe diameters of 170, 70 and 40 mm, respectively. For smaller diameters, the batteries and the radio receiver may be placed on an additional body attached to the others. The autonomy of the prototypes is about 2 hours. This architecture is very simple and the rotary motion can be exploited to carry out scrubbing or inspection tasks.

Keywords: Autonomous mobile robot, In-pipe inspection, Helical motion

Introduction

Pipe inspection robots have been studied for a long time, and many original locomotion concepts have been proposed to solve the numerous technical difficulties associated with the change in pipe diameter, curves and energy supply. Although an exhaustive review of the literature is impossible due to the limited space available, a few broad categories can be identified:

(i) For small size, many projects follow the earthworm principle consisting of a central part moving axially while the two end parts are provided with blocking devices connected temporarily to the pipe. Pneumatic versions of this concept have been proposed (e.g. [1]), but they require an umbilical for power. For smaller diameter (10 mm or less), a piezoelectric actuation has been considered, according to the inchworm principle, or according to an inertial locomotion driven by a saw-tooth wave voltage [2], or using vibrating fins with differential friction coefficients [3].

(ii) For medium size piping, classical electromechanical systems have been proposed with various architectures involving wheels and tracks, with more or less complicated kinematical structures, depending on the diameter adaptability and turning capability (e.g. [4,5]).

(iii) For large pipes, walking tube crawlers have also been proposed [6].

The four mobile robots presented in this paper belong to the second category, they span a tube diameter from 40 to 170 mm. The design results from an attempt to reduce the electromechanical complexity through the use of a single actuator to achieve mobility along the tube. Although our study can be regarded as an independent effort, it appears that the “spiral wheel” strategy was explored before [7].

Architecture

The robot consists of two main parts, a stator and rotor, connected by an active joint including a D.C.

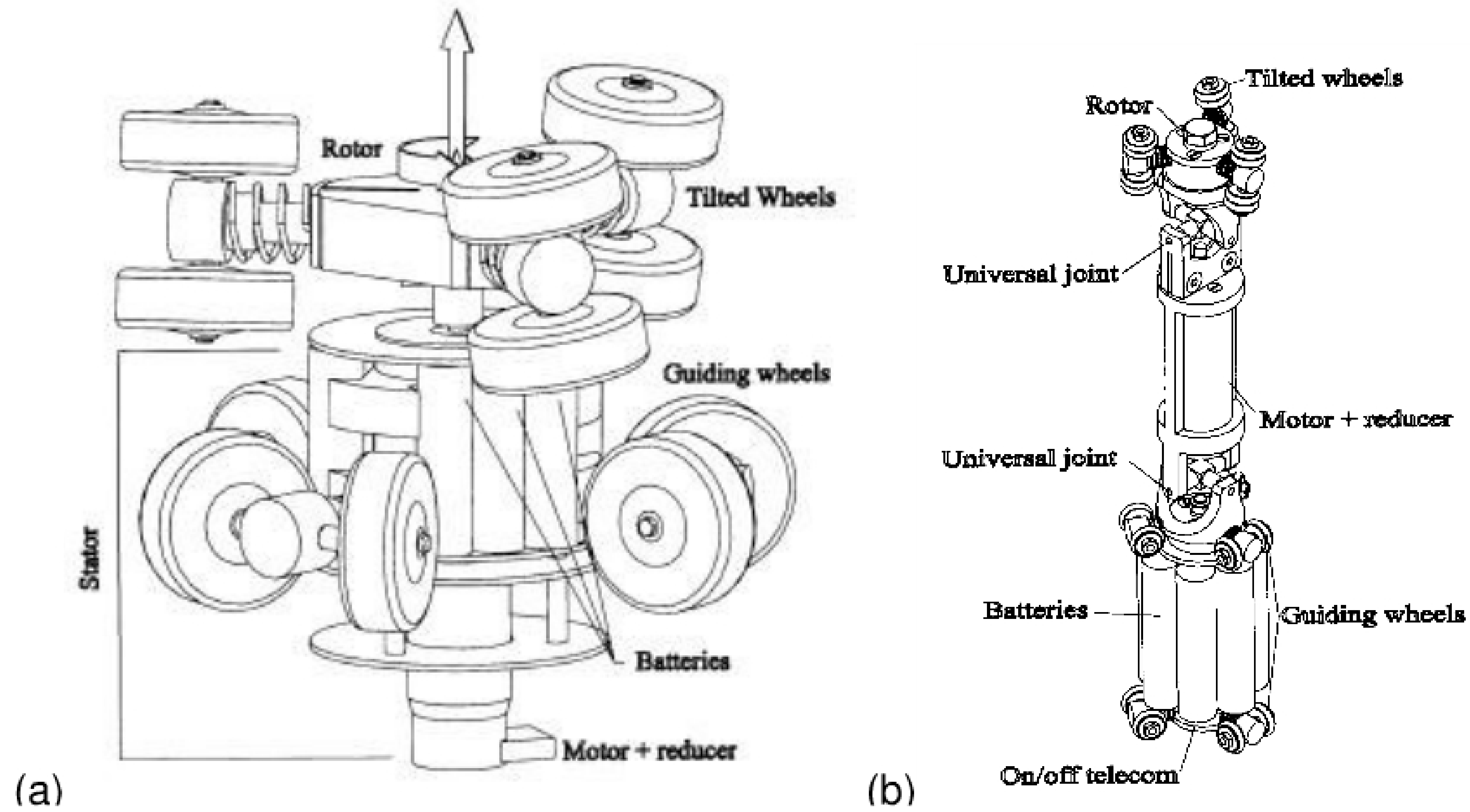


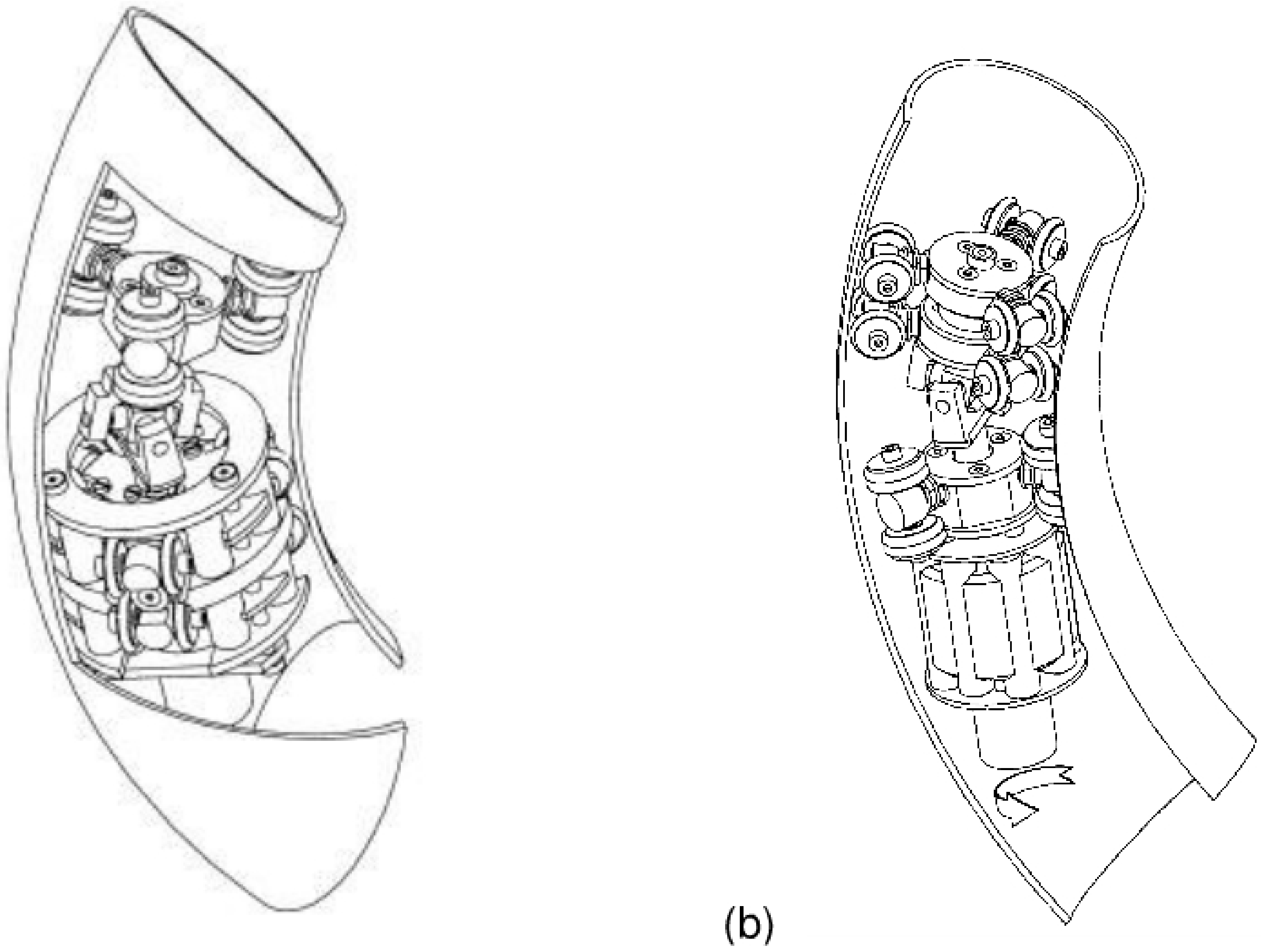
Figure 1: Robot architecture. (a) *Two-body architecture for larger diameter (D-170)* (b) *Three-body architecture for small diameter (D-40).*

motor with reducer and, in some cases, a universal joint. The stator is equipped with a set of wheels which allow the motion parallel to the tube axis; the rotor is equipped with wheels tilted with a small angle with respect to the plane perpendicular to the tube axis (Fig. 1. a). In this way, the stator is constrained to move along the tube axis while the wheels of the rotor can only move along helical trajectories, and the rotation of the rotor with respect to the stator generates the axial motion. The relation between the axial velocity v of the robot and the rotation velocity ω of the rotor is:

$$v = \omega \cdot R \cdot tg\alpha$$

where R is the radius of the pipe and α is the tilting angle of the wheels of the rotor, taken as 10° throughout this project. The wheels on the stator and on the rotor must be located in order to guarantee the overturning stability, to assure a sufficient contact force between the robot and the pipe, to adapt to small changes in the pipe diameter and obstacles, and to allow travelling in curved pipes. For the larger robot (D-170), the robot is rigidly connected to the axis of the motor and three pairs of wheels on both the rotor and the stator are sufficient for stability. For smaller diameters, curved pipes require more degrees of freedom, because the connection between the rotor and the stator does not stay on the tube axis during turning. This is achieved with a universal joint provided with some axial backlash along the two axes of the joint; overturning stability requires the doubling of the number of wheels on the stator.

For diameter above 70 mm, the robot is provided with 9 batteries (AA NiCd 600 mAh) which are distributed around the motor on the stator. Tests have shown that they give a reasonable autonomy of the order of 2 hours. For smaller diameters, this configuration is no longer possible and the robot is made of three bodies separated by two universal joints (Fig. 1. b): the first one consists of the rotor with the tilted wheels; the second one includes the motor and reducer, and the third one is the stator with the axial wheels, the energy supply and the telecom.



(a) (b)

Figure 2: Design alternatives for D-70. *(a) The motor and the batteries are mounted on the stator. (b) The motor and batteries are mounted on the rotor.*

(a) (b) (c) (d)

Figure 3: HELI-PIPE family portrait. *(a) D-170, (b) D-70/1, (c) D-70/2, (d) D-40*

Two design alternatives have been investigated for a diameter of 70 mm (Fig. 2). In the first one, the motor and the batteries are mounted on the stator while in the second one they are mounted on the rotor; this second alternative is not acceptable if the robot is used with a tether for power supply. Table

1 gives the main characteristics of the various robots; by "payload", it is meant the maximum allowed axial force in addition to the weight when the robot is moving upwards in a vertical position.

Robot #	**D-170**	**D-70/1**	**D-70/2**	**D-40**
Pipe diameter	163-173 mm	68-72 mm	68-72 mm	38-43 mm
Curve radius	>600 mm	>170 mm	>170 mm	>110 mm
Payload	5 N	3N	3 N	1 N
Speed	8 cm/s	10 cm/s	5 cm/s	3 cm/s
Motor power	10 W	6 W	6 W	3.2 W
Gear reduction	33.2:1	19:1	32:1	84:1
Obstacle height	<10 mm	<3 mm	<3 mm	<1 mm
Number of bodies/ universal joints	2 / 0	2 / 1	2 / 1	3 / 2
Weight	1300 g	470 g	480 g	250 g

Table 1: Main characteristics of the robots

References

[1] C. Anthierens, C. Prelle, A., Jutard, M. Bétemps, "Pneumatic Actuated Microrobot for In-Pipe Locomotion", *4th Japan-France / 2nd Asia-Europe Congress on Mechatronics*, Kitakyushu, Japan, 6-8 october, 1998.

[2] H. Nishikawa, T. Sasaya, T. Shibata, T. Kaneko, N. Mitumoto, S. Kawakita and N. Kawahara, DENSO CORPORATION, Japan, "In-Pipe Wireless Micro Locomotive System", in *Proc. International Symposium on Mechatronics and Human Science (MHS '99),* Nagoya, Japan, Nov. 24-26, 1999.

[3] S. Aoshima , T. Tsujimura, T.,Yabuta , "A Miniature Mobile Robot Using Piezo Vibration for Mobility in a Thin Tube" *Transactions of ASME, Journal of Dynamic Systems, Measurements and Control,* Vol. 115, pp. 270-278, June 1993.

[4] K. Suzumori, T. Miyagawa, M. Kimura, Y. Hasegawa, "Micro Inspection Robot for 1-in Pipes" in *IEEE/ASME Transactions on Mechatronics,* vol. 4, No. 3, pp. 286-292. September 1999.

[5] S. Hirose, H. Ohno, T. Mitsui, K. Suyama, "Design of In-Pipe Inspection Vehicles for ø25, ø 50, ø 150 Pipes", *Journal of Robotics and Mechatronics* 12, 3, pp. 310-317, 2000.

[6] F. Pfeiffer, T. Rossmann, "Control of a Tube Crawler", *Proceedings of the Fourth International Conference on Motion and Vibration Control, Movic' 98*, Zurich, 1998, pp. 889-894, Vol. 3, Switzerland, August 25-28.

[7] JGC Corporation, "Inspection Robots in Nuclear Power Plants" *Robotics in Nuclear Facilities,* Special issue for the exhibition of the 11th *International Conference on Structural Mechanics in Reactor Technology (SMIRT II),* Tokyo, August 1991.