Advanced Repair Methods for Enhanced Reactor Safety

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Keywords: Reactor repair, maintenance, shape memory alloys

Introduction; project objectives

Maintenance of the reactor and primary system piping becomes increasingly important as plant operating time is accumulating. Development of new and effective methods for maintenance and repair is constantly going on to meet the challenge of raising the level of reactor safety and reliability while at the same time contributing to the economy in the operation of nuclear power plants.

ABB Atom Service Division is developing new repair and mitigation techniques for primary systems in nuclear power plants. A group of projects are under development in the area of reactor pressure vessel, reactor internals and primary piping.

The overall objectives of this program are:

- Form an alternative to weld repairs
- Widen the options for individual repair solutions
- Lower the overall cost for repairs and mitigation.

What is new?

This program is based on the use of Shape Memory Alloy - SMA - technology. Shape Memory Alloys are materials that have the property of "remembering" a previously given shape - i.e. when activated by heat the piece of material recovers its former shape. In this process a substantial amount of force can be exerted by the material.

These inherent properties have been used to take a new approach to some vital reactor repair and maintenance areas:

- Repair of IGSCC cracks in CRD (control rod drive) nozzles
- Fastening of new seat material in valves
- Stress improvement of pipe welds
- Strength reinforcement of pipe welds
- Strength reinforcement of reactor vessel

The use of SMAs potentially makes it possible to increase the service life of components, to avoid costly and time-consuming weld repairs, and to reduce the radiation dose imposed on maintenance personnel.

Development work including SMAs has been going on at ABB Atom since 1989 It has included two extensive material programs concerning the study of mechanical and primary system environmental properties. Applications have been investigated and proof-of-principle tests have been performed.

Repair methods

SMA contracting rings are used to repair CRD nozzles with IGSCC cracks or indications that require some kind of mitigation. The repair techniques are designed to stop any leakage through the nozzles and can be applied to GE as well as Atom BWR reactor designs. This type of repair, see figure 1, can also be applied to PWR top head CRD penetrations. Among the advantages of using SMA in this case are:

- No welding of nozzle or reactor pressure vessel
- Large installation clearance - radial and excentric
- No machining of sealing surfaces
- No post-installation adjustment
- Remote installation with water and bulk of fuel in place.

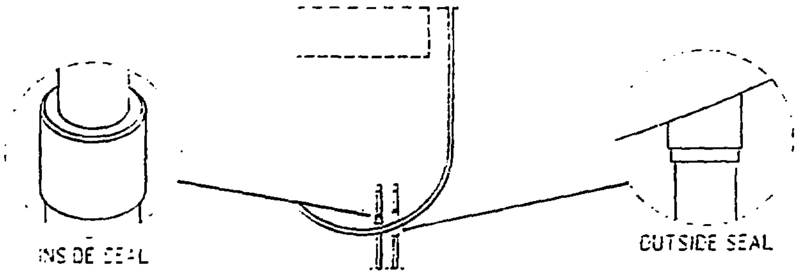

Figure 1: CRD Nozzle Seals

An expanding SMA ring is used to position and keep in place a valve seat substitute ring. This is a technique to renew a valve seat that may have been damaged due to wear or erosion. Such damage could cause leakage through the valve. Valve seat replacement is also desirable to replace seat materials containing cobolt, due to the high contribution of this material to the total radiation dose in the plant. By using an SMA ring for the installation, see figure 2, a number of advantages can be gained:

- No welding needs to be performed on the valve body
- No residual stresses from welding
- Seat material can be selected independent of weldability considerations
- Seat ring installation tolerance is improved, leading to no or minimum need for machining of seat surface
- Large part of work is prepared and done in workshop, minimizing time and effort spent in-plant
- Reduction of radiation dose on installation workers
- Requires less worker skill than welding
- Fewer QA/QC requirements than welding.

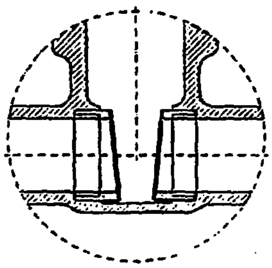

Figure 2: Valve Seat Fastener Ring

The SMA wire winding technique - MWT or Multi Wire Tension - is based on prestressing a pipe or vessel wall in compression, thereby counteracting the tensile stresses that arise in different operating modes. Both circumferential and axial prestress can be achieved. The concept of prestressing a pressure vessel, which is a proven technology to strengthen cylindrical vessels, can be combined with SMA technology. In this case the unique properties of SMAs are used to create the prestress that is othérwise given by e.g a pre-loaded steel wire. SMA wire can be treated to recover, i.e. reduce up to 6% of its length when heated. The recovery process is designed to create tensile stresses in the high-strength SMA wire which gives the desired preload in the pipe or vessel wall.

The use of an SMA wire thus does not require any forceful tools and consequently leads to a convenient prestressing operation, well suited to in-plant installation. SMA wire adapted to this application has been specified and manufacturing technology has been developed within the MWT development project.

MWT can be designed to give stress improvement to a weld - MWT-SI, figure 3. The main features of this method are:

- Tensile stresses can be reversed to compressive stresses
- On stainless steel IGSCC is prevented
- Crack propagation is slowed down or arrested
- Design and calculation methods permit high precision in application of stresses
- Winding is left on pipe or vessel - no relaxation of stresses over time
- Size independence - the same wire dimension can be used for all applications
- Easy installation and low cost

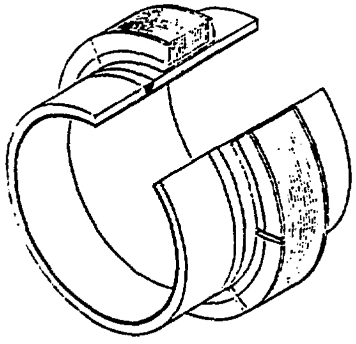

Figure 3: MWT for Weld Stress Improvement

MWT can also be designed to give strength reinforcement - MWT-SR, figure 4. MWT-SR can be designed to

- Counter-act crack initiation
- Improve crack arrest
- Guarantee leak-without-break

MWT-SR
- Can replace ISI of a weld as it can be designed to be redundant to the pipe itself - keeps two pipes together "without the weld"
- Reduces vibration loads with up to 50%
- Can be designed for all dimensions - main recirculation piping as well as small pipes
- Does not require machining, heat treatment or opening up of pipe
- Does not change the structural properties of the pipe in any way for future repair or inspection requirements
- Is easy to install and remove - at a low cost.

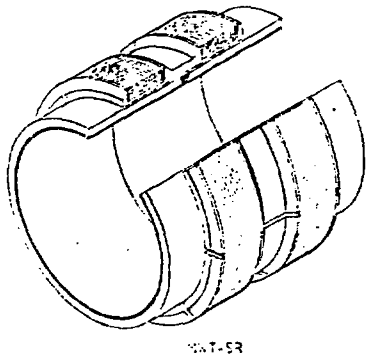

Figure 4: MWT for Weld Strength Reinforcement

MWT-Stress Improvement and -Strength Reinforcement can be combined in the same winding to give a pipe or a vessel the full advantages of both techniques.

MWT can also be designed to pre-stress and reinforce the reactor pressure vessel. This technology would be applicable in those cases where neutron radiation has caused weld embrittlement. MWT would lower the stress levels in the vessel wall, thereby decreasing the probability of brittle fracture or crack propagation. MWT has several potential advantages over other alternatives, e.g. annealing:
- Stress calculation and design can be done to achieve desired pre-stress
- Result of pre-stressing operation can be measured
- Pre-stress remains during operation
- Lower overall cost.

Conclusions

A few innovative concepts for repair and mitigation have been described in this paper. These concepts, based on SMA technology, represent new approaches to needs that exist now or will come up in the near future. The basic feature of all methods is that welding and component replacement is being avoided. These types of repair and maintenance activities often represent a large part of plant outage costs as well as requiring substantial efforts in Quality Assurance and dose limitation planning. The SMA-based repair methods described here would give plant operators new ways to meet increased safety standards and rising maintenance costs.