LEAK SEALING INACCESSIBLE ACCELERATOR COOLING SYSTEMS

G W Willetts, S E James, NNC Limited, Birchwood Park, Birchwood, Warrington, Cheshire, WA3 6BZ, United Kingdom, Tel. +44 1925 700111, Fax. +44 1925 895551, www.nnc.co.uk

Abstract

Cooling water systems associated with experimental facilities often suffer from minor leakage in inaccessible areas. Such leaks can interfere with vacuums, electronics or reduce cooling efficiency. Replacement of these defective pipes may cause extensive experimental programme downtime and associated financial costs.

The paper describes a novel technique to permanently repair such leaks remotely by injecting a water based sealant into the pipe. The sealants used are fully compatible with pipework, valves and instrumentation. The internals of the pipe are not coated in any way; hence the heat transfer properties of the cooling system are unaffected.

This technique has been perfected over the past 30 years in the nuclear power industry. The paper describes how this technology has now been successfully applied to cooling systems within experimental facilities, such as at ISIS, Rutherford Appleton Laboratories (Oxford, UK). A variety of components associated with the LINAC at Los Alamos Neutron Science Centre (USA) were sealed during a demonstration of the technique.

1 INTRODUCTION

In common with other major engineering undertakings, complex experimental facilities can suffer from small problems, which in the short term, are no more than a minor irritation. However, if left unresolved such problems may increase in significance in the longer term. A case in point is the occurrence of minor water leaks which frequently occur in ancillary cooling circuits.

In themselves small leaks, typically of 40 thousandths inch effective diameter in a system at a working pressure of 200 kPa may not represent an immediate safety or economic penalty. If left unattended such leaks could cause a variety of problems. Water from leaks can cause corrosion to components that are intended to be dry. The water may interfere with electrical or control instrumentation. If left unsealed leaks tend to grow and start to affect the water chemistry. Indeed the authors have encountered all such problems in treating more than 400 leaks in 35 facilities worldwide.

2 EVOLUTION OF THE SEALANT

In 1968 National Nuclear Corporation Ltd (NNC) encountered water leaks in the cooling circuit buried in the reactor's pre-stressed concrete pressure vessel. Water leaks into the concrete were traced to pinholes in welds in the buried deep in the concrete. Excavation of the concrete was not a credible option, therefore considerable research was carried out to review and evaluate new and existing methods of leak repair.

Car radiator sealants showed some promise but failed to be durable. Such proprietary preparations tend to be concentrated solutions of relatively insoluble silicate salts. Their sealing action is by exudation through the crack and formation of a crust on the external surface by evaporation in the air flow. They fail after relatively short periods and cannot withstand pressure. Internal coatings produced seals but the internal coating they produced on the pipe sloughed off and blocked valves etc. They also impaired the heat transfer. Other materials, such as fibres of various types produced temporary seals that were dislodged by pressure surges.

Ultimately the problem was solved by the discovery that a dilute aqueous suspension of a refined mineral clay could seal the defects. The rheological properties of the suspension are such that when it is introduced into the defective pipework and an overpressure applied, the sealant is forced into the turbulent flow regime within the path length of the defect where it swells to staunch the flow and eventually seals the defect. The balance of the material within the pipe is not modified and is therefore readily flushed from the pipe without leaving a coating.

In the late 1980s NNC developed the so-called "ZORIC" sealants which are water-based blends of mineral clay and epoxy resins. The sealant contains about 80 weight per cent water and therefore cannot set to a hard glassy mass within a pipe. The clay component acts to staunch the seal and support a resin dispersion. During air curing of the plug, the resin coalesces and gels to form a glassy, adhesive seal. "In the field", defects of up to 200 thousandths inch round hole equivalent diameter have been successfully sealed.

3 VALIDATION OF SEAL PROPERTIES

Chemical and Physical Properties

Every different application for the sealant has posed questions about some chemical or physical property. As a result, comprehensive laboratory data have been obtained to confirm the use of the sealant on research facilities and nuclear reactors.

These include data on the ability of the sealant to withstand pressure and pressure cycling. The initial application for the sealant is to operate in low pressure cooling circuits at up to 15 bar (g). However laboratory tests have shown the sealant to withstand 40 bar (g) though, in the field, actual seals are usually tested at about 1.5 times the working pressure. The resin component of the sealant imparts good adhesive properties and in rig tests seals have withstood rapid pressure fluctuation for systems operating at temperatures between 20 and 70°C. The ability of seals to withstand temperatures in excess of

0-7803-7191-7/01/$10.00 ©2001 IEEE.

this is generally in line with the softening properties of the resin. The sealant is good up to about 95°C though the hottest seal "in the field" operates at about 120°C. On a temperature cycling rig, seals have withstood diurnal temperature cycles of plus and minus 25°C for more than five years.

Tensile and Flexural Properties

The tensile and flexural properties were assessed by conventional tensometry on cast specimens and by lap shear tests on 12 mm by 12 mm areas of sealant bonding stainless steel tags. In addition a test rig was built to enable optimisation of the sealant recipe to withstand repeated flexure. Seals in simulated corrosion pits, up to 2 mm diameter, have exceeded typical nuclear reactor design lifetime of 160 bending cycles at up to 1% deflection (tensile) at deflection rates of 1% per second at 45°C and 5 bar (g) circulating water pressure.

3.3 Irradiation Resistance

The sealant has been subjected to gamma irradiation trials and neutron activation analysis Test seals in stainless steel piping have withstood pressure testing after an irradiation dose of 650 MGy gamma irradiation in a spent fuel pool. This dose by far exceeds the normal design lifetime dose of 10 MGy to concrete in pre-stressed concrete pressure vessels. Neutron activation analysis showed the only significant activation product to be ^{24}Na consistent with the small natural sodium content of the mineral component.

3.4CHEMICAL COMPATIBILITY

As regards chemical compatibility there is a small chlorine content by virtue of the chemical synthesis of one of the resin components from epichlorhydrin. Radiolytic destruction of this compound could produce free chloride, a known agent for stress corrosion cracking of stainless steels. For critical application this is minimised by batch selection of the resin component to a level broadly in line with nuclear requirement (US Atomic Energy Commission, 1973). The heavy metals content (e.g. mercury, cadmium, etc) of the sealant is also routinely measured and found to be very low. In nuclear applications heavy metals would be a concern on two counts; firstly with regard to the potential to form radioactivation products; and secondly, with regard to the propensity to form low melting point alloys and hence liquid metal embrittlement of structural steels.

4 APPLICATION OF SEALANT

Sealant is applied by hydraulic transfer, to prevent shearing of the mixture pumps are not used.

The initial step in any leak sealing campaign is to characterise and size the defect. Water leak rates may be used, but a better indication of the leak size can be gained from gas pressure decay measurements following injection of e.g. nitrogen. The Euler Equation is then used to produce a convenient formula to derive the defect size. For example for nitrogen gas:

$$d = \sqrt{\frac{2.66 dP.V}{p^{1.143} dt \sqrt{\frac{P_o^{0.7142}}{\rho_o}}}}$$

where:

d is the equivalent round hole diameter of the defect (m)

P_o is the initial pressure (Pa abs)

P is the mean pressure (Pa abs)

dP is the pressure drop (Pa) over the time span dt (s)

ρo is the density of nitrogen at Po (kg.m^{-3})

V is the volume of the system under test (m^3)

Similar equations can be developed for other gases (e.g. helium). The diameter of the defect is expressed as an effective diameter since its precise geometry is not known. In theoretical terms the above equation is a gross oversimplification and makes assumptions as to the discharge coefficient and the flow regime within the defect. Nevertheless the important point is that such data enable the selection of the precise sealant formula and application pressure and, where multiple applications are required, it provides an indication of progress towards a successful seal.

The sealant is mixed to specific conditions and introduced to the circuit. An overpressure is then applied to force the sealant into the defect. This pressure is normally held for thirty minutes at which time the sealant is drained from the system and the circuit flushed with water to remove all traces of sealant. An air flow is then established in the system to cure the plug. The curing time is dependent on system temperature and is normally about 24 hours. In general, defects more than 40 thou inch effective diameter require more than one treatment.

5 TYPICAL APPLICATIONS

The technique was developed for civil nuclear power stations, and has been extensively used in the UK, Germany, India and the US. The technique has now been applied to experimental facilities. Two specific examples of facilities were NNC have been involved are given:

5.1 Leak Sealing at the ISIS Facility RAL

NNC have worked with RAL (Rutherford Appleton Laboratory, Oxford, England) at the ISIS facility since 1988. Over the years NNC have routinely sealed a number of defects in copper and stainless steel cooling circuits associated with the LINAC and synchrotron.

The alternative approach to this technique would be to locate exactly the leak site and replace the section. In this way, the NNC leak sealing technique reduces experimental downtime. RAL use NNC services as part of their commitment to ensure safe and reliable operation of the ISIS facility. Typical examples of the types of cooling circuits successfully sealed by NNC's technique include:

- Copper Cooling Circuit Leaking into a Vacuum on a Tuner

A leak was detected from a cooling circuit into the vacuum of a Radio Frequency (RF) tuner, located in the injector section of the Synchrotron. The leak was identified by monitoring the vacuum with a portable mass spectrometer. The volume was 6.5 litres and was sealed in one application, without the vacuum being released. The criteria for a successful seal was by monitoring the composition of the vacuum, where it was possible to detect if air or water was passing through the defect.

- Drift Tube Assembly, LINAC Cooling Circuit

A leak was detected on a drift tube assembly cooling circuit within one of the tanks on the LINAC. NNC treated with one application of ZORIC.

- Sealing of Cooling Circuit Leaks in the HEDS Beam Stop

The HEDs beam stop graphite block is hard soldered to a copper cooling plate. The graphite block is placed into the negative Hydrogen ion beam to stop it during run-up testing and machine physics. A leak on the cooling plate was sealed with the technique.

- Cooling Circuit Leaks on the Intermediate Target on the MUON Facility

The Intermediate target is a graphite target mounted on top of a copper cooling disc. The extracted proton beam passes through the Intermediate target and a small percent of the beam interacts with the graphite giving off a stream of pions which decay into muons as they are transported to the muon beam lines. A 7 litre stainless steel "ladder" configuration assembly cooling circuit with an estimated 1 thou inch diameter round hole equivalent defect, was sealed in one application. The success of the treatment was judged by the quality of the vacuum.

5.2Leak Sealing Demonstration at LANL

NNC demonstrated the leak sealing technique to LANSCE (Los Alamos Neutron Science Centre) in 2000, for use on copper cooling systems associated with the LINAC. LANSCE purchased a license to enable their personnel to carry out leak sealing using the NNC ZORIC sealant range. As part of this purchase, NNC conducted an extensive training programme to enable a selected number of LANSCE operations staff to apply the technique.

Currently, LANSCE have not used the technique on the system, however during the visit to Los Alamos NNC carried out a number of successful sealant applications on a range of test pieces representative of cooling circuits found on the LINAC. All sealed successfully

One of the main objectives for LANSCE was to find a technique that could seal leaks quickly and remotely, without the need for costly maintenance periods and hence excessive experimental downtime. Specifically a technique was required, which could be used in the situation where there was a failure of the cooling circuit in the LINAC drift tube assembly. If a drift tube required replacement in a tank, then this would result in a lengthy maintenance procedure to dismantle the tank, remove and replace the defective drift tube and associated electronics. Further, re-adjustments would have to be made to ensure the beam had not been affected. During the visit a number of representative test pieces were treated and sealed:

Table 1: Test Pieces Sealed at LANSCE

Test Piece Description	Volume (ml)	Defect size (thou diameter)
Spare Drift Tube Assembly	1000	1.3
Quadrupole Magnet Cooling	40	4
"U" loop assembly	100	8
Cooling Saddle assembly (two drilled holes)	175	37 (combined)

6 CONCLUSIONS

NNC has unique experience in remote leak sealing technology. From development of the technique for a specific problem in the civil nuclear power industry, the technology has been successfully transferred to experimental facilities including accelerator systems.

Working in partnership with the client a cost effective permanent repair in defective systems can be achieved to minimise facility downtime