# Burst Failures of Water Cooling Rubber Pipes of TRISTAN MR Magnet Power Supplies and Magnets

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## ABSTRACT

In 1992, from June to September, the rubber pipes of magnet and magnet power supply for water cooling burst in succession. All the rubber pipes to be dangerous to leave as those were had been replaced to new rubber pipes before the end of the summer accelerator shutdown.

## INTRODUCTION

It passed about 7 years from the beginning of the TRISTAN MR accelerator operation. It is strange that these failures happened at the same short period in the different situations such as that one was in the MR tunnel and the other was in the power supply stations on the ground. A number of and various types of rubber pipes are used for power supplies and magnets. Thus the detail analyses were carried out with respect to the various items. This document describes the processes of the analyses of the failures and the final improvements.

## RUBBER PIPES OF THE MAGNETS

### Classification of the rubber pipe

3 types of the rubber pipes which were supplied from the same company have been used for 4 types of the magnets. Table 1a,1b. show the parameters of the magnets.

Table 1a. Magnet parameters

| Type | length | magnet name | height of magnet center |
|---|---|---|---|
| $Q_A$ | 0.8m | QF,QD,QS6 —7, QW1—4 | 0.9m |
| $Q_B$ | 1.0m | QC4—6, QRF,D | 1.5m |
| | | QS1—5 | 0.9m |
| $Q_C$ | 1.5m | QC3 | 1.5m |
| B | 5.84m | B | 0.9m |

Table 1b. Magnet parameters

| Type | number of magnets | number of rubber pipes | Diameter of rubber pipes |
|---|---|---|---|
| $Q_A$ | 240 | 1920 | 1/4" |
| $Q_B$ | 88 | 704 | 3/8" |
| | 40 | 320 | 3/8" |
| $Q_C$ | 8 | 64 | 1/2" |
| B | 264 | 1056 | 1/2" |

The rubber pipes which happened to burst up to this time were those of $Q_B$ type magnets except for a few cases.

### Past failures of the rubber pipes

We have experienced water leak failures of the rubber pipes of $Q_A$ magnets in 1991. Magnet name is QW4 which is located in the neighborhood of wiggler magnet, where the radiation level was very high at the accelerator operation. The water leak process was a little different from the failures at this time, because the rubber pipe did not burst in any case, but the water leaked from the couplers in both ends. And also the rubber pipes had many cracks on the surface and lost flexibility. It had been considered to be that these phenomena came from radiation damage.

These effect does not come out after the radiation shield with Pb.

### Investigation of the burst failure

*Rubber materials*

The rubber pipe which has been strengthened with 3 layers has been used for the magnet. The raw material of it is ethylene propylene rubber of which abbreviated name is EPDM. Table 2. shows the structure.

Table 2. Structure of the rubber pipe

| | |
|---|---|
| outside layer | ethylene propylene rubber |
| middle layer | vinylon fiber ( for reinforcement ) |
| inside layer | ethylene propylene rubber |

In 1982, the examination in quality about EPDM rubber was carried out with respect to the radiation damage. The mechanical strength of the samples was measured before and after irradiation. The sample was irradiated with $\gamma$-ray from $^{60}Co$ and the total dose was $1.3 \times 10^4$ C / kg. It has been confirmed that both samples endured the pressure of over 100 kg / cm$^2$ and repetitive pressurization of 10000 times.

*Investigation of the change in quality*

Some of the rubber pipes for $Q_B$ magnet which have been used from the beginning of the accelerator operation could not endure the cooling water pressure of only 10 kgf / cm$^2$. The failures happened 6 times after all. The outside layer burst lengthwise in about 10 cm and the middle and the inside layers in about 5cm in all cases. Water flew out heavily at every time. This phenomenon was a little different from the case of QW4 magnet mentioned above.

Then we ordered the technical company to analyze new and

used rubber pipes in order to investigate the reason why the failure happened. The analyses were carried out on the following items.

Table 3. Items of the analyses

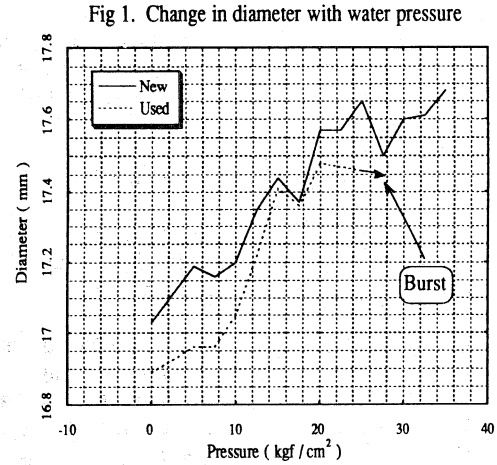
| | |
|---|---|
| 1) surface observation | observation of surface condition with scanning electron microscope(SEM) |
| 2)qualitative analysis | X ray micro analysis(XAM) of elements |
| 3)qualitative analysis of materials | spectrum analysis of the infrared ray absorption |
| 4)quantitative determination of the rubber admixture | Soxhlet extraction ( solvent : acetone ) |

It became clear that for the degraded rubber pipe each layer seemed to be changed in quality on surface appearance and the rubber admixture also to be decreased in quantity.

*Investigation from the point of view of the structure*

Up to here the degradation of the rubber pipes was examined from a viewpoint of radiation damage and chemical process. But finally it proved the design of the rubber pipe to be insufficient.

Fig 1. Change in diameter with water pressure




The thickness of the inside layer of the rubber pipes used for $Q_A$, $Q_B$ and $Q_C$ magnets are 3mm, 1.75mm and 3mm respectively. This difference affects the life of the rubber pipes essentially. It looks like that the life of the rubber pipe for $Q_B$ magnet had been reduced extremely in accordance with the degradation of the rubber and the vinylon fiber after long time use. To confirm this fact the pressurization test was carried out for a new one and a degraded one. Fig 1. shows the result.

New one endured the pressure with 35 kgf / cm$^2$ for 10 minutes.

Replacement work

On July end we decided to replace all rubber pipes for $Q_B$ magnets and ordered the company to manufacture the improved rubber pipes of which thickness of the inside layer is 3mm.

The replacement work of the 1024 rubber pipes was carried out at the end of September for 5 days. There happened no failure after the replacement for one year.

## RUBBER PIPES OF THE POWER SUPPLIES

Outline of the failure

For MR magnet system 72 power supplies which are cooled by pure water have been installed in 4 power supply stations. The rubber pipe for water cooling has been adopted as insulator against the ground .

In June, 1992 it happened the burst failures of the rubber pipes twice at the same period of the magnet failures. But in this case it has been considered that the failures were caused by quite different reason.

Investigation of the failure

Table 4. shows the specification of the rubber pipe. It also consists of 3 layers for reinforcing.

It could not be explained that the rubber pipe could not endure the water pressure of only 10 kgf / cm2 with the condition of no radiation. Then the detail analysis same as the case of magnet was carried out.

Table 4. Specification of the rubber pipe

| | |
|---|---|
| normal pressure | 18 kgf / cm$^2$ |
| test pressure | 35 kgf / cm$^2$ |
| minimum break-down pressure | 72 kgf / cm$^2$ |
| minimum load for drawing fittings | 135 kgf |
| working temperature | -40 °C — 93 °C |
| outside layer | rubber formulated CR family ( polychloroprene rubber ) |
| reinforcing layer | synthetic fiber braided ( rayon ) |
| inside layer | rubber formulated NBR family ( acrylonitrile butadiene rubber ) |

*Investigation of the change in quality*

Technical company analyzed the new and used rubber pipes in regard to the items same as the magnet case. It became clear that each layer seemed to be changed in quality on surface appearance and the rubber admixture also to be decreased in quantity for the degraded rubber pipe.

*Investigation of the deposit inside the rubber pipe*

The brown colored deposit was confirmed on the surface of inner layer by the observation of two burst rubber pipes. It proved to be that this phenomenon was the decisive evidence of the failure at this time. Fig 2. shows the qualitative analysis of the deposit. As can be seen the main component of the deposit is Cu.

*Mechanism of the deposit*

For the power supply Cu metal has been used for water cooling fin of SCR, hollow conductor of transformer etc. The mechanism of the dissolution of Cu metal into water and the

deposit of the Cu oxide on the surface of rubber pipe were estimated as Fig 3.

Fig 2. Qualitative analysis of the deposit

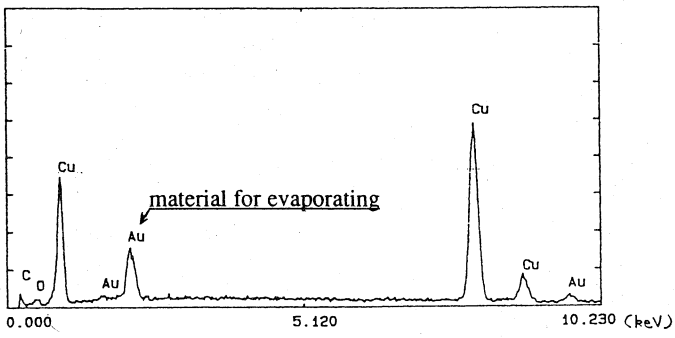



Fig 3. Dissolution and deposit of the Cu

$$Cu + \frac{1}{2} O_2 \longrightarrow Cu^{2+} + 2OH^-$$

Dissolution of Cu metal into water

$$Cu + 2OH \longrightarrow Cu(OH)_2$$

Cu is in existence as copper hydroxide in pure water of pH

below pH

Cu is in existence as Cu ion in the water

over pH

$$Cu(OH)_2 \longrightarrow CuO + H_2O + Q\ cal$$

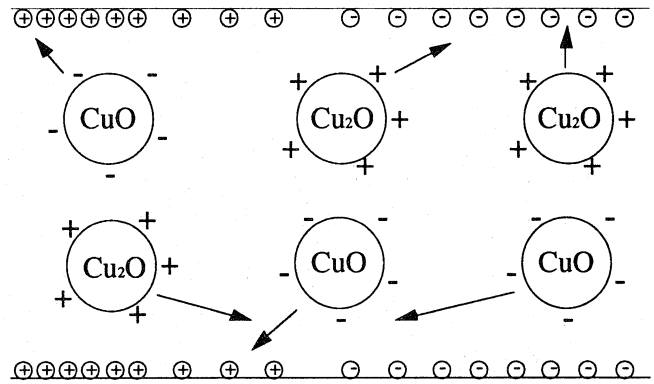
$$2CuO \longrightarrow Cu_2O + (O)$$

Cu is in existence in the water as copper oxide ( $Cu_2O$ ) or cuprous oxide ( Cu O).

The molecules of the copper oxide and the cuprous oxide and the inner layer of the rubber pipe are charged, so the Cu oxide will be deposited on the surface of the rubber pipe by the electrostatic force. The condition of the charging depends on pH, flow velocity and temperature of water, and electric field. Fig 4. shows the appearance of the deposit of Cu oxide.

It is said to be that the degradation of the NBR group rubbers has been caused by the exchanging of S for Cu atoms in the molecular bond. And also it was found that the deposit could be seen only on the rubber pipe supplied with DC voltage.

Fig 4. Appearance of the deposit




From the investigation described above it proved to be that it is impossible to use the NBR group rubbers to the water cooling system which uses Cu metal for conductor.

In addition, quite different phenomenon was found. For B magnet power supply the ground fault failures through Cu oxide deposit happened frequently a little before the burst failures.

*Replacement work*

We decided to replace all the rubber pipes which were supplied with DC voltage at both ends. The EPDM rubber pipe was adopted at this time by the reason mentioned above.

In case of power supply the rubber pipe has been made use of only by putting into the nipple on main water pipe. By cutting into required length from the rubber pipe roll the 80 rubber pipes for B, QF and QD magnet power supplies and 1080 for other small-sized Q magnet power supplies were replaced.

The replacement work was carried out in the middle of September for 13 days. There happened no failure after this work.

## CONCLUSION

It will be necessary to pay attention to the following matters at the time of designing magnet or magnet power supply.

1) The rubber pipes of NBR family cannot be adopted if there was a possibility that Cu ion dissolves into the cooling water.
2) In generally the degradation speed of rubber pipe will be enhanced under the environment of water. Thus in time of designing rubber pipe it must be taken into account to make the thickness of this large enough.
3) Even if water resistant materials is used, there will be a possibility of ground fault failure caused by the deposit of Cu oxide. Therefore the periodical maintenance of the cooling water system should be carried out.