APPLICATION OF ATMOSPHERIC PLASMA-SPRAYED FERRITE LAYERS FOR PARTICLE ACCELERATORS

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Abstract

A common problem in all kinds of cavity-like structures in particle accelerators is the occurrence of RF-resonances. Typically, ferrite plates attached to the walls of such structures as diagnostic devices, kickers or collimators, are used to dampen those undesired modes. However, the heat transfer rate from these plates to the walls is rather limited. Brazing ferrite plates to the walls is not possible in most cases due to the different thermal expansion coefficients. To overcome those limitations, atmospheric plasma spraying techniques have been investigated. Ferrite layers with a thickness from 50 μm to about 300 μm can be deposited on metallic surfaces like stainless steel exhibiting good thermal contact and still reasonable absorption properties. In this paper the technological aspects of plasma deposition are discussed and results of specifically developed RF loss measurement procedures for such thin magnetically lossy layers on metal are presented.

INTRODUCTION

Ferrite materials are commonly used as absorbers, e. g. to dampen undesired higher order modes in RF cavities or for RF loads used in particle accelerators. Challenges common to these applications lie in the involved production process of the ferrite-containing structures. Thick ferrite layers (several mm) are not easy to fix to metal surfaces with good thermal contact in vacuum. In addition, they cause difficulties when heating up due to the different thermal expansion coefficients of the ferrite and its carrier material. On the other hand, thin ferrite layers are very brittle and require delicate handling. In this paper plasma sprayed surfaces acting as microwave absorbers are proposed as an alternative. The plasma spraying technique is well established in industry and the resulting ferrite coating is quite robust in handling. The paper opens with a presentation of the plasma spraying technique. Subsequently, the measured absorption properties for different microwave absorbers are presented. For application outside vacuum silicon rubber layers loaded with ferrite powder were investigated. This work is concluded with the proposal of an alternative high power load. The load is designed such as to allow usage of a high temperature ($> 150\,^\circ$C) cooling liquid under high pressure (> 20 bar) which could be used for heating buildings or for regaining energy by using e. g. a Stirling engine.

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PLASMA SPRAYING TECHNIQUE

Plasma Spraying of Ni Zn-ferrite powder is a suitable alternative process for producing EMC coatings that are normally manufactured using conventional ceramic processing routes [1].

Plasma Spraying is a widely used thermal spray process where the spray material, in powder form, is molten in a plasma jet, in or outside the spray gun and is then accelerated towards the workpiece surface. There the liquid droplets solidify immediately and build up the coating. Plasma sprayed coatings consist of a certain porosity of approximately 5 %. The main adhesion mechanism of thermal spray coatings is mechanical interlocking so that substrate surfaces have to be roughened by a surface pretreatment process such as grit blasting. In the plasma jet temperatures up to 20000 K are obtained which allow melting of ceramic powder feedstock. Typical particle velocities in plasma spraying are $150 - 450\,\mathrm{ms}^{-1}$.

The investigated plasma sprayed coating was produced using the Sulzer Metco F4 gun (Sulzer Metco, Switzerland). The process is illustrated in Fig. 1. The Ni Zn-ferrite

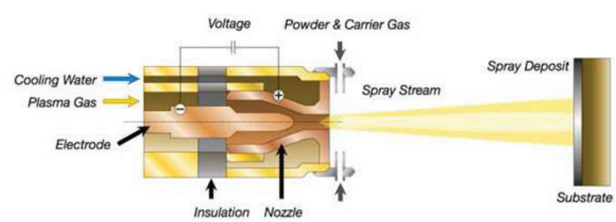

Figure 1: Illustration of the plasma spraying process (source: Sulzer Metco).

powder was sieved to a powder fraction of $90 \pm 45\,\mu$m. For spraying the Ni Zn-ferrite powder, the plasma gas mixture was argon and hydrogen. The powder was radially injected into the plasma close to the core zone using nitrogen as a carrier gas. The F4 gun was attached to a robotic arm which traversed the stationary mild steel substrate at a speed of $600\,\mathrm{mms}^{-1}$ with a vertical step of 5 mm between passes. The stand-off distance was set to 90 mm and the substrate was cooled by compressed air to avoid overheating. Plasma gas flow rates and current were adjusted for a low thermal impact on the Ni Zn-ferrite powder. The achieved coating thickness was measured to be $\approx 90\,\mu$m.

To determine whether the plasma sprayed ferrite is suitable for use in vacuum, it is important to know its chemical composition as well as its secondary electron yield

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and of course to determine the outgassing properties which is on its way. For the evaluation of the secondary electron yield (SEY) the sample and collector current has been measured simultaneously for an electron beam at normal incidence. The dose during the measurement has been kept below $10^{-6}\,\mathrm{Cmm}^{-2}$ to avoid conditioning. The resulting maximum SEY is 2.05 at a primary energy of 400 eV±30 eV (Fig. 2). The surface chemical composition

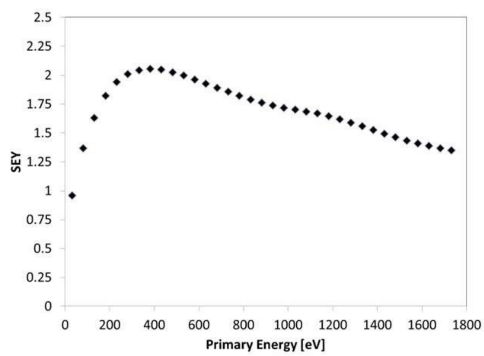

Figure 2: Secondary electron yield for the ferrite probe under investigation.

of the ferrite layer after solvent cleaning has been measured by X-ray Photoemission Spectroscopy, by using a non-monochromatized Mg K_α source. Spectra were taken for an emission angle of 45 degrees. The resulting composition in atomic percent is given in Table 1.

Table 1: Material parameters for the plasma sprayed ferrite sample. The surface concentration of each element is given in atomic percent.

Element	B	C	Fe	Na	Zn	O
%	8.3	19.1	5.2	2.8	8.1	56.5

PROPERTIES OF DIFFERENT FERRITE PROBES

In total seven different probes with different compositions were investigated:

Plasma Sprayed Ferrite sample This sample is a metal plate coated with ferrite (4C65) applied via the plasma spraying method. It was produced at the surface engineering institute (IOT) in Aachen and has a layer thickness of $\approx 90\,\mu$m. It can stand temperatures up to its Curie-Temperature which is 350 °C.

Painted Ferrite sample A sample where ferrite powder mixed with adhesive was spray-painted onto a metal surface. The resulting coating has a layer thickness of 1.5 mm. It is specified to withstand temperatures of up to 250 °C by the manufacturer Shenzhen Cui Baolong Industry Co. Ltd. This material can withstand temperatures of up to 250 °C and is quite robust in handling.

Painted SiC sample For this sample silicon carbide mixed with adhesive was deposited on a metal plate, similar to the spray-painted ferrite sample. It is supposed to exhibit good absorption properties in the high frequency range according to the manufacturer Shenzhen Cui Baolong Industry Co. Ltd. The material can handle temperatures up to 250 °C.

Commercial crisp plate For this probe a crisp plate (manufacturer: Whirlpool) was taken out of a commercial microwave oven. Such a plate is usually used to bake food inside a microwave oven. It has a ferrite filled rubber matrix on its bottom which acts as a microwave absorber. It is able to withstand temperatures of up to 300 °C.

Silicon rubber sample For this sample a microwave absorbing silicon rubber was vulcanized to a metal plate. It is an imitation of the commercial crisp plate rubber and was specified to withstand temperatures of of up to 250 °C according to the manufacturer Shenzhen Cui Baolong Industry Co. Ltd.

Ferrite loaded rubber sample This sample consists of a self-adhesive silicon rubber absorber that was put on an aluminum plate for measurements. The material is capable of handling temperatures up to 250 °C. It was supplied for testing by Shenzhen Cui Baolong Industry Co. Ltd.

Eccosorb The measured Eccosorb ® of Type MCS-SS6M is a commercially available self adhesive rubber matrix containing ferrite powder. It can withstand temperatures of up to 170 °C and has excellent absorbing properties from 800 MHz to 18 GHz according to the manufacturer Emerson & Cuming.

All samples were equipped with two connectors and a copper stripline (thus forming a microstrip line, Fig. 3). The S-parameters of each sample were measured in time

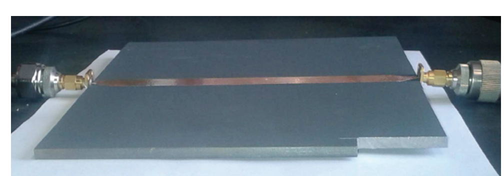

Figure 3: The second setup used to measure the different probes comprises of two connectors on each probes side and a copper stripline on top of each probe.

as well as frequency domain. In time domain, the reflection losses at both connectors could be determined rather precisely (Fig. 4). The height of the step is a direct measure for the reflection coefficient Γ of the connectors. The transmitted power is then $\propto (1-|\Gamma|^2)$. The reflection loss corrected S_{21} values were obtained via measurements in frequency domain (Fig. 5). Taking into account the indi-

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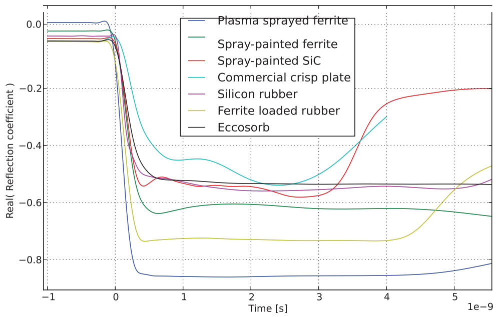

Figure 4: Reflection coefficient S_{11} in time domain for the different ferrite probes.

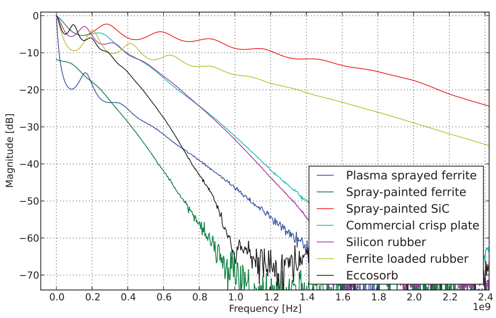

Figure 5: Transmission coefficient S_{21} in frequency domain for the different ferrite probes.

vidual stripline length of each sample and selecting an operation frequency (in the present case 700 MHz), the loss per meter can be determined. This provides a means for direct comparison of the absorption properties of all samples. The corresponding values are summarized in Table 2.

Table 2: Summary of the losses per meter and the maximum temperature for the different samples under investigation.

Probe	losses [dB/m]	T_{max} [° C]
Plasma sprayed ferrite	−123.5	350
Painted ferrite	−232.6	250
Painted SiC	−20.5	250
Commercial crisp plate	−167.3	300
Silicon rubber	−90	250
Ferrite loaded rubber	−27.35	200
Eccosorb	−145.3	177

HIGH TEMPERATURE LOADS IN AIR

Due to its easy availability and low cost, the use of a ferrite loaded silicon rubber inside a first high power load prototype is currently in preparation. Two different designs of such a prototype for 700 MHz resonance frequency will be constructed:

- a traveling wave structure and
- a standing wave structure

The first is essentially a 1 m long waveguide coated with the silicon rubber material (2 mm thickness). The second is a waveguide including coated plates as proposed in [3]. Since such a configuration was shown to have a low Q value when using the Eccosorb material on one side of the plates [3], comparable results are expected for double-sided silicon rubber coated plates. The benefit of such a load would be its suitability for higher temperatures without waiving the excellent absorption properties.

In addition, a load coated with plasma sprayed ferrite for applications in vacuum is currently under investigation. The painted samples (ferrite and SiC containing) measured in the context of this work turned out to be too brittle for practical applications (thermal shock, pulsed RF power) at all.

CONCLUSIONS

Several materials have been tested in the framework of this paper. Most of them exhibit excellent absorbing properties. All samples were produced with well established techniques, are uncritical in handling and can withstand temperatures higher than 100° C. Samples using ferrite materials and crisp technology seem to have the highest absorption rates in the frequency range of interest. Also, ferrite filled rubber matrices like Eccosorb exhibit excellent absorption properties. The plasma spraying technique proved to produce reliable and robust surfaces, exhibiting excellent losses for such a small layer thickness ($\approx 90\,\mu$m). According to these findings and their high temperature behavior, different prototypes for high power and high temperature loads applying these techniques were investigated.

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