Experimental report

06/07/2016

Proposal: **1-02-157**

Council: 4/2014

Title: Residual Stress Influence on Magnetic Properties of HVAF-Sprayed Metallic Materials for Load Cell Application

Research area: Materials

This proposal is a new proposal

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Samples: Fe-Ni

Instrument	Requested days	Allocated days	From	To
SALSA	7	7	13/07/2015	20/07/2015

Abstract:

Magneto-elastic solid materials are commonly used as sensors in the development of load carrying body. As their magnetic properties change under mechanical loads, such material ability can then be used as internal or intrinsic sensor system, if integrated to the loaded part as a surface property, as applicable utilizing Thermal Spray Coating technologies. In magneto-elastic force sensors, applied stress modifies magnetic permeability of the sensing material, which can be detected with precision by Pressductor® technology. Magnetic permeability of the given magneto-elastic material is a function of residual and applied stresses as well as texture and crystallite size. The working point of the sensor is therefore defined by texture, crystallite size and residual stresses in the magneto-elastic material.

Experimental Report on Proposal 1-02-157 “Residual Stress Influence on Magnetic Properties of HVAF-Sprayed Metallic Materials for Load Cell Application”

Background

The object under evaluation is a magnetoelastic sensor made of staineless steel and NiFe coating using Pressductor® technology. The aim of the proposal was to evaluate residual stresses before and after loading cycle and stress gradient development during loading cycle.

Experiment

The sample is shown figure 1. It is a stainless steel body were the bottom of the 16 mm hole in the middle of the body is coated 1 mm thick NiFe coating. Four holes that are characteristic for Pressductor® measuring technology are seen at the bottom of 16 mm hole. The coating was sprayed by thermal spray.

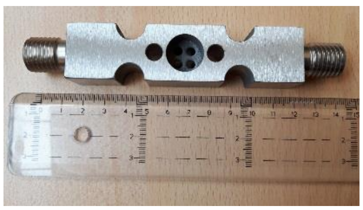

Figure 1. Photo of the measured sample.

For quantitative stress evaluation a triaxial measurement is needed. With current configuration of stress rig and hexapod on SALSA and given sample geometry it is not possible to make triaxial stress measurements. Thus it was decided to use results of mechanical modeling of the sample where ratio of stresses is known in point A and point B (see Fig.1). When tension is applied on sensor point A is under tension and point B is under compression where, according to calculations, the compressive stress in Z direction experienced by point B is 1.51 times less than tensile stress experienced by point A in Y direction.

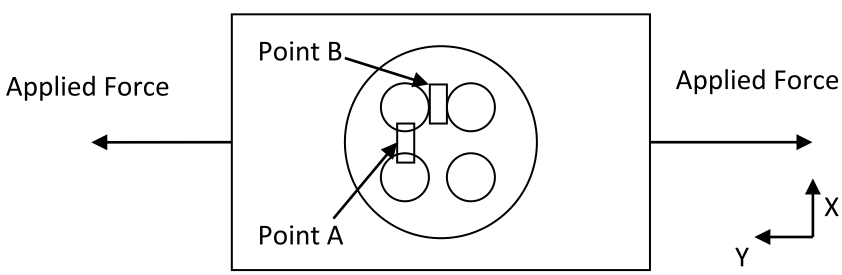

Figure 2. Sketch of measured points on the sensor.

Neutron beam at a wavelength of 0.167 nm scanned on Ni (111) peak. Neutron beam was collimated down to 0.7 mm and scanned outside the sample into the sample through the thickness of the coating (1 mm).

The sensor was measured at two points A and B (Fig.2). The measurement was done in Y-direction as it is notated in Figure 2. First measurements were done at 0 kN load and then the sample was loaded to 50 kN, 34.5, 7.35 and 1 kN.

In table 1 values of calculated average stress are presented for points A and B in all three directions for tension of 50 kN as showed in fig.2.

		X, MPa	Y, MPa	Z, MPa
Point A	Maximum	80,5	372,6	5,1
	Average	47,6	291,4	-0,1
	Minimum	-13,3	243,5	-2,1
Point B	Maximum	-163,3	37,7	2,3
	Average	-192,8	-22,3	0,2
	Minimum	-267,4	-57,4	-5

Table 1.Calculated values of stresses at points A and B when 50 kN tension is applied to the sensor. In green are marked points where experimental measurement of stresses was possible and in red where experimental measurement was not possible due to experimental setup.

Results

Results of the measured stresses are presented in table 2. All of the measured points exhibit gradient in residual stresses. The initial stress gradient does not change with applied load and the hysteresis effect is not observable i.e. after applied load the residual stress is back to the same level within the measurement error. There might be a tendency though in point A close to the substrate for in plane measurement that there is a hysteresis effect but it is just one point that is deviating.

Table 2. Calculated and measured values of stresses at points A and B when 50 kN tension is applied to the sensor.

		Y, MPa	Y, MPa	Z, MPa	Z, MPa
		Calculated	Measured	Calculated	Measured
Point A	Maximum	372,6	448,4	5,1	28,38
	Median	291,4	252,6	-0,1	-73,8
	Minimum	243,5	202	-2,1	-155,7
Point B	Maximum	37,7	155,6	2,3	89,3
	Median	-22,3	127,2	0,2	71,8
	Minimum	-57,4	-50,44	-5	-10,3

A general trend is that the coating is under more compressive residual stresses close to the substrate and they get more on tensile side closer to the surface. It is not possible to tell the absolute level of the coating stresses since a “stress-free” sample was not measured. The gradient of stresses is though measured and can vary between 200 to 400 MPa in Y and Z direction, which is a substantial amount of stresses given that E-modulus is correct. Stresses in X direction were not measured before loading of the sample, but the profile of stresses should be comparable to that of in Y direction.

According to simulation results (Table 1) under the load the out of plane stress component has low amplitude and on average is ~0 MPa. Thus under load experimentally one would expect to see almost no changes in peak positions for out of plane direction. In Figures 6 & 8, as well as table 2, can be seen that coating experiences stresses that are measurable and are in order of tenths of MPa as opposed to some MPa as would be expected by simulations. According to simulations the coating should experience compressive strains in point A and tensile in point B. The same sign of stresses are observed in measured samples just with a factor of 10 in magnitude.

For the in plane stress measurements according to the calculations (Table 1) in point B there should be slight compressive stresses and in point A substantial tensile stresses. According to measurements tensile stress of approximately 300 MPa is measured which is in accordance with calculations, but in point B a slight tensile stress is measured which is conflict with the calculations. On the other hand calculation values are spread around zero. The experimental result of slightly tensile stresses is worth noting and probably is a consequence of residual stresses and their redistribution under load.

Conclusions

The neutron diffraction stress measurements on Pressductor geometry were successful. A residual stress profile could be measured and showed that compressive stresses close to the substrate are dominating in the film. No hysteresis/plasticity was observed while comparing loaded/unloaded sample. A more thorough scanning of interface between substrate and the film should done in order to address that question.

Out-of-plane stresses were measured by approximately factor 10 higher than those calculated. The in-plane stresses were more consistent with calculations even though when calculated stresses are low the measured stresses are of opposite sign and higher. The hypothesis would be that residual stresses influence and overshadow the applied stresses thus measured stresses are not consistent with calculated ones when measured in the points were applied stresses are low.