Targeted Local Stress Imprint in Electrical Steel as Means of Improving the Energy Efficiency

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Summary: Using dark field imaging with a neutron grating interferometer, we have investigated the inverse magnetostrictive effect in ferromagnetic metal sheets. The aim of this study was to develop a novel way to tailor the magnetic properties of electrical steel in use for electric machines. We found, that imprinting could be used to guide the magnetic field inside electrical sheet laminations, similar to the currently used technique of cutting holes and notches, but without the drawback of lowering the mechanical properties.

In view of environmental sustainability and climate protection, the efficiency of electric machines is a main concern. Especially with regard to electro mobility, efficient motors are necessary for further developments and acceptance by the general public. One key component of electric drives is their magnetic core, which most commonly consists of stacked sheets of thin ferromagnetic Fe-Si based electrical steel. In order to improve the performance, the single sheets have been tailored to guide the magnetic field in certain directions, usually by cutting notches in the right places. Nevertheless, this method has a negative impact on the structural robustness of the magnetic core. As a consequence, on the one hand the engine speed is limited, which in turn hinders the optimization of the machines as a whole. On the other hand, more expensive high strength electrical steels need to be used in order to allow the machine to be operated at higher speeds.

One approach to overcome these drawbacks is the application of the inverse magnetostrictive effect, also known as Villari effect. This effect describes how stress changes the magnetic susceptibility of ferromagnetic materials [1]. The underlying mechanism is a change in lattice parameters, which in turn influences the ferromagnetic exchange between lattice sites and the magnetic anisotropy of the material. Up to now, stress in electrical steel has only been addressed with regard to optimal magnetization properties, which are achieved by having minimal stress in the metal. By introducing local stress into the electrical steel, a field guiding effect can be achieved. However, this process has nearly no impact on the durability of the material, making it far more favourable for designing electric machines [2, 3]. As electric machines are produced in a large scale industrial manner, it is additionally essential to implement this method in a sufficiently efficient way into existing production chains. This is luckily no problem, since well-established stamping processes exist that can be used to imprint the desired local stress, while retaining the aforementioned minimal global stress.

In our work, we have investigated the effect of local stress in Fe-Si based electric steel sheets on the magnetic properties by means of neutron gratin interferometry (nGI) [4]. The dark field image (DFI) obtained by this method is sensitive to scattering off magnetic domain boundaries, thus enabling us to analyse the spatial distribution of said domains [5]. The presence of a magnetic field in the ferromagnet causes an alignment of domains which reduces the scattering. In the DFI this translates to high grey values for aligned domains and high magnetic fields and low grey levels for a disordered domain structure and low fields. By using this technique on sample sheets imprinted with test shapes we could observe the field distribution in the vicinity of local stress. The magnetic field was applied to the metal sheets, by clamping them into a magnetic yoke, made up of a package of similar electric steel sheets, equipped with solenoids. This setup ensured a situation similar to the actual application. The obvious impact can be seen in Figure 1, which shows DFI images under various external magnetic fields. Even in the case of no applied field (a) the imprint which causes the local stress can be seen as dark regions, which implies a high density of domain walls, contrasted by a light region at the thinnest part between both imprints. A similar picture is retained in higher applied magnetic fields (b) and (c). Our results indicate the feasibility to design magnetic flux reduction and guiding within the sheets. Further investigations are ongoing to evaluate the whole range of possibilities specific local stress opens up in the design of electric machines. This includes a systematic study of materials and imprinted geometries.

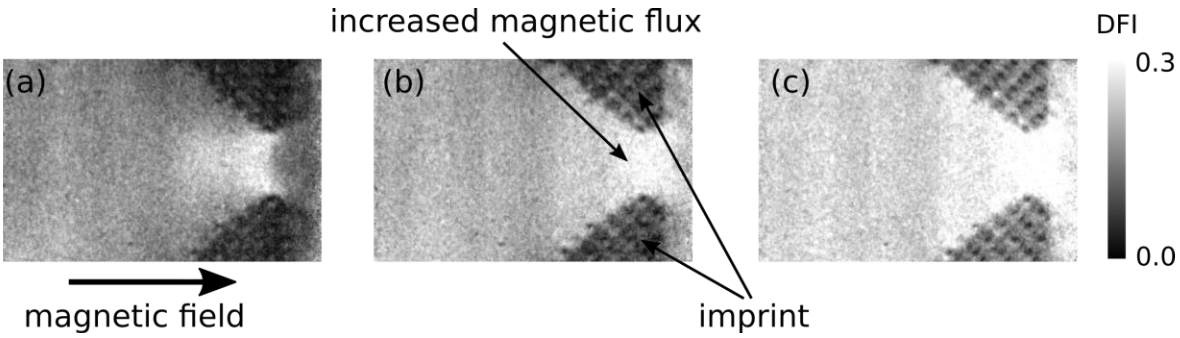

Fig. 1: Dark field images at three different magnetic fields (solenoid currents from left to right: 0A, 0.25A, 0.5A)

1. References

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