Nonlinear Modeling of Piezoelectric Transducers under High-power Operation

その他のタイトル	ハイパワー駆動時における圧電振動子の非線形モデルに関する研究
学位授与年月日	2015-09-25
URL	http://doi.org/10.15083/00073097

論文審査の結果の要旨

氏名　劉　耀陽

This dissertation is the investigation on the modeling and characteristics of nonlinear behavior appeared in piezoelectric transducers. The originality in this dissertation mainly includes three points, as shown in follows:

1. To enhance the quality factor of fabricated lead-free piezoelectric ceramics, a new method (introducing a post-annealing in argon process) was proposed and verified.
2. Prior to estimating the high power properties of lead-free materials, the criteria at high power need to be established. Grounded on the burst mode results, a nonlinear model was proposed to explain the deformation in the admittance curves, as well as the existence of jumping and hysteresis. After examining the validity of the model, the estimation of lead-free materials was realized.
3. The nonlinear model also allows the high power characteristics in piezoelectrics.

There are seven chapters in this dissertation. In chapter 1, the principle, categories, constitutive equations, applications, and the lead-free tendency of the piezoelectrics were introduced. Niobate piezoelectrics (especially potassium niobate $KNbO_3$ and sodium niobate $NaNbO_3$), as one family of the most promising lead-free substitutes for $Pb(Zr_xTi_{1-x})O_3$, and hydrothermal methods adopted in this study were then introduced. The serious limitation of high power characteristics and thus developed evaluation methods were presented at last.

In chapter 2, the hydrothermal synthesis process of $KNbO_3$ and $NaNbO_3$ powders and the ensuing solid state reaction of $(K_{0.48}Na_{0.52})NbO_3$ (KNN) ceramics were presented first. Then the experimental details of the burst mode method, the estimation of various properties, and their calculation methods were explained.

In chapter 3, pure and CuO-doped KNN ceramics were prepared on the basis of $KNbO_3$ and $NaNbO_3$ powders fabrication. CuO-KNN ceramics was fabricated via a hydrothermal method and solid state sintering. It was found that an extra post-annealing process did not change the phase of the CuO-KNN ceramics; however, the intense transitions of the domains in the ceramics that occurred after post-annealing caused a change in quality factor (Q_m). Q_m was decreased to a small value by the post-annealing process and recovered gradually over several hours; which can be attributed to the rearrangement of oxygen vacancies in the domains. The validity of a new method to enhance the Q_m of CuO-KNN ceramics was then investigated and discussed. A post-annealing process in an oxygen-deficient atmosphere was used to increase the amount of oxygen vacancies, which could impede the movement of the domain structures, and thus increased Q_m. In the case of annealing in argon, Q_m was increased to approximately 1500 from 870, whereas post-annealing in oxygen resulted in a decrease of Q_m.

In chapter 4, prior to the estimation of the high power characteristics for CuO-KNN ceramics, the investigation on nonlinear behavior in PZT transducers was carried out. Nonlinearity in high voltage admittance curves and burst mode method were presented and discussed consecutively. The burst mode method was adopted to measure the vibration velocity of the transducers after excitation by a burst voltage. The determined equivalent mechanical loss and equivalent spring constant were found to be functions of velocity amplitude, suggesting that nonlinearity should be considered when the transducers are driven at high power. Admittance curves at high voltages corroborated the presence of nonlinearity in the PZT transducers. In the admittance curves of the hard-type transducer, a jumping behavior appeared as well as an admittance hysteresis between different sweeps. A model taking into account the nonlinearity was proposed and adopted to fit the admittance curves, which yielded the nonlinear coefficients. It was demonstrated to be effective in describing the admittance hysteresis and the jumping observed in the case of the hard-type PZT transducer and the deformation admittance curve for both PZT transducers. In the admittance curve, the mechanical nonlinearity was the main source instead of the dielectric and piezoelectric nonlinearities. Through the theoretical derivation of the piezoelectric constitutive equations, dimensionless coefficients were suggested for the comparison of samples with different sizes.

In chapter 5, using the proposed nonlinear model in chapter 4, the estimation of fabricated CuO- KNN transducers were carried out. The comparison of nonlinear levels between CuO-KNN and PZT transducers was then given and discussed. Similar to the hard-type PZT, the admittance curves of the CuO-KNN transducers at high voltages also have serious deformation, significant jumping, and admittance hysteresis. The proposed nonlinear model enabled the determination of nonlinear coefficients; using which the prediction of admittance curves at other voltages was realized. In the burst-mode method, the nonlinearity at high voltages was confirmed. The results obtained from the burst mode results were found to be consistent with the admittance curve measurements. Compared with PZT, lead-free CuO-KNN transducers were less dependent (better) on high-velocity condition, which makes CuO-KNN a promising material for high-power devices. This method can be used to analyze the nonlinearity in piezoelectrics, and the two nonlinear coefficients can be regarded as the criteria for assessing the piezoelectric transducers driven at high voltage. The comparable results of the admittance curve measurement and burst mode method suggest that the two methods can be substitutes for each other in estimating the nonlinearity level. The feasibility of the model without considering the dielectric nonlinearity and piezoelectric nonlinearity also indicates that the jumping and admittance hysteresis in the admittance curve results from the mechanical nonlinearity.

In chapter 6, the simulations of nonlinear circuits were carried out for better understanding of the appeared nonlinear phenomena. The nonlinear behavior was further studied in this chapter; *G-B* circles of hard-type and soft-type PZT transducers were depicted to illustrate the jumping behavior. Using the proposed nonlinear model, the simulations of current jumping in frequency response and voltage response were performed. The parameters (ξ, η, and V_0) can affect the nonlinear phenomena (shift of resonance frequency, change of half bandwidth, appearing, and disappearing of the jumping) separately and together. For practical usage, a simplified method for estimating the nonlinear level was proposed; the nonlinear coefficients can be obtained via simple calculation from the feature points in the low voltage and high voltage admittance curves. The determination of quality factor under high power operation was discussed; based on the nonlinear coefficients it is also possible to calculate Q_m at high power condition. Comparison of the nonlinearities between the present studies and other conditions was also presented.

In chapter 7, the main results of this thesis were concluded; a prospect was made.

This thesis proposed and verified the estimation method for high power characteristics in the piezoelectrics; detailed explanation was also presented.

In total 1068 words