International Symposium on
Computer, Consumer and Control, 2020
November 13-16 2020, Taichung, Taiwan

High Precision Machine Learning Based Maximum Lyapunov Exponents Prediction Model of Spherical Porous Gas Bearing System

Authors : Ping-Huan Kuo[1], Cheng-Chi Wang[2]*
Affiliations: [1]National Pingtung University, [2]National Chin-Yi University of Technology

Abstract—Spherical porous air bearing (HSPAB) systems have been focused and extensively used for a variety of mechanical engineering application, and potential for use in high-rotational speed, high-precision and high stiffness instrumentation. In HSPAB system, rotor is supported by gas bearings which provide higher rotational speed and lower heat generation environment than oil bearings and does not cause to deformation. Duo to the pressure distribution in the gas film is nonlinear, and specific critical speed, rotor imbalances or inappropriate design are operated, HSPAB systems will exhibit non-periodic or chaotic motion and cause structural fatigue to the system. So, in order to understand and control under what kind of operating condition the non-periodic motion will occur to the HSPAB system, first, the governing equations of HSPAB system is solved to obtain the dynamic behavior of the rotor center and then will be examined under different operating conditions by generating the maximum Lyapunov exponents (MLE). However, the calculation process of MLE is extremely time consuming and complicated. In order to solve this problem efficiently and correctly, a high precision machine learning based maximum Lyapunov exponents prediction model is proposed in this study. Besides, several machine learning algorithms are also adopted to be the core of the prediction model. The experiments show that the proposed prediction model gives good results. The feasible and practicality of the proposed model are also validated in this study. Multilayer Perceptron (MLP), Support Vector Machine (SVM), Decision Tree (DT), and Random Forest (RF) are adopted to model the MLE map. In this experiment, only 1/2 of total samples are used in the training process. We also depict the whole prediction result by several machine learning model. The final results show that the performance of RF is more superior than other algorithms. By using this proposed method, the MLE value can be real-time estimated with significant time savings.

In the proposed SPAB model, the gas flow is assumed to be isothermal and the gas viscosity is constant. The pressure distribution in the gas film between the shaft and the bushing is modeled using the following **Reynolds equation**:

$$\csc\phi\frac{\partial}{\partial\phi}\left(\csc\phi\, P\overline{H}^{3}\frac{\partial P}{\partial\phi}\right)+\csc^{2}\phi\frac{\partial}{\partial\theta}\left(P\overline{H}^{3}\frac{\partial P}{\partial\theta}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left(rP\overline{H}^{3}\frac{\partial P}{\partial r}\right)$$
$$=\sigma\frac{\partial}{\partial\tau}\left(P\overline{H}\right)+\Lambda\frac{\partial}{\partial\phi}\left(P\overline{H}\right)+\Lambda\frac{\partial^{2}P_{p}^{2}}{\partial r^{2}}$$

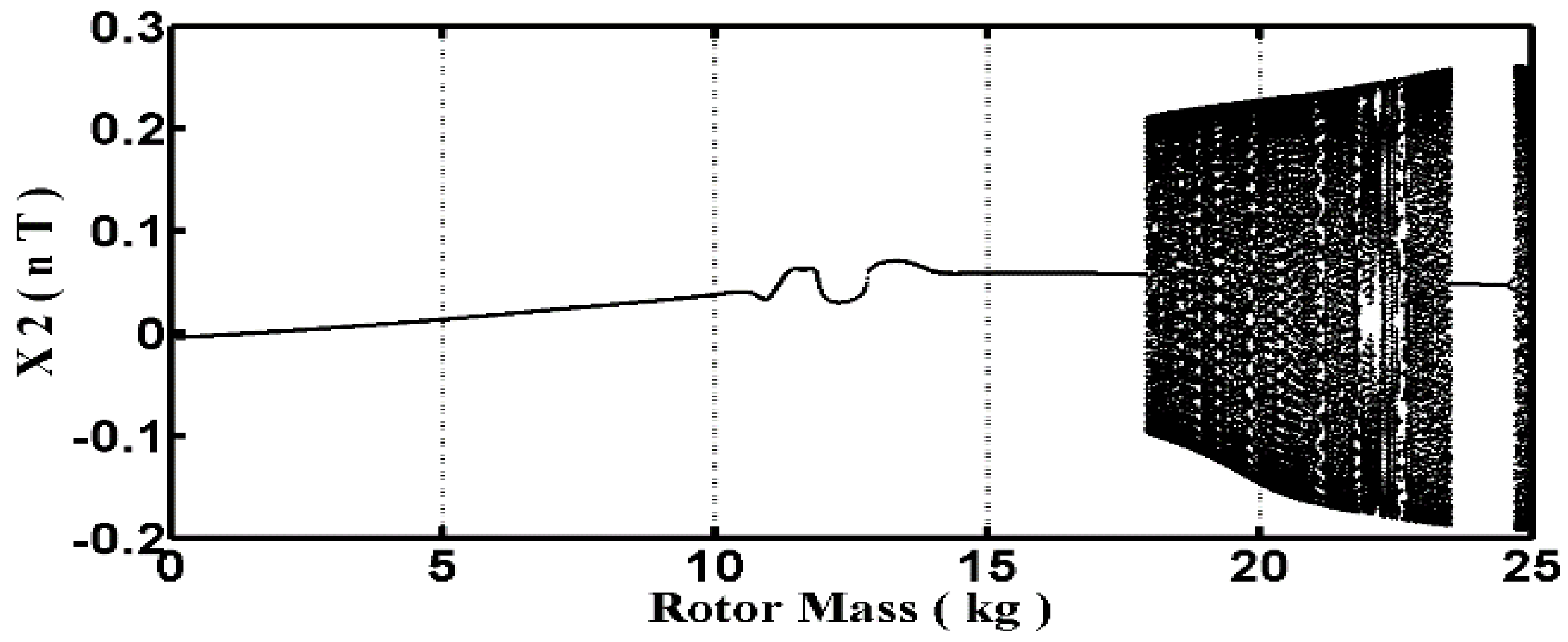


Figure 1. Bifurcation diagrams of rotor center X2 in the horizontal direction versus the rotor mass (for bearing number Λ = 3.45).

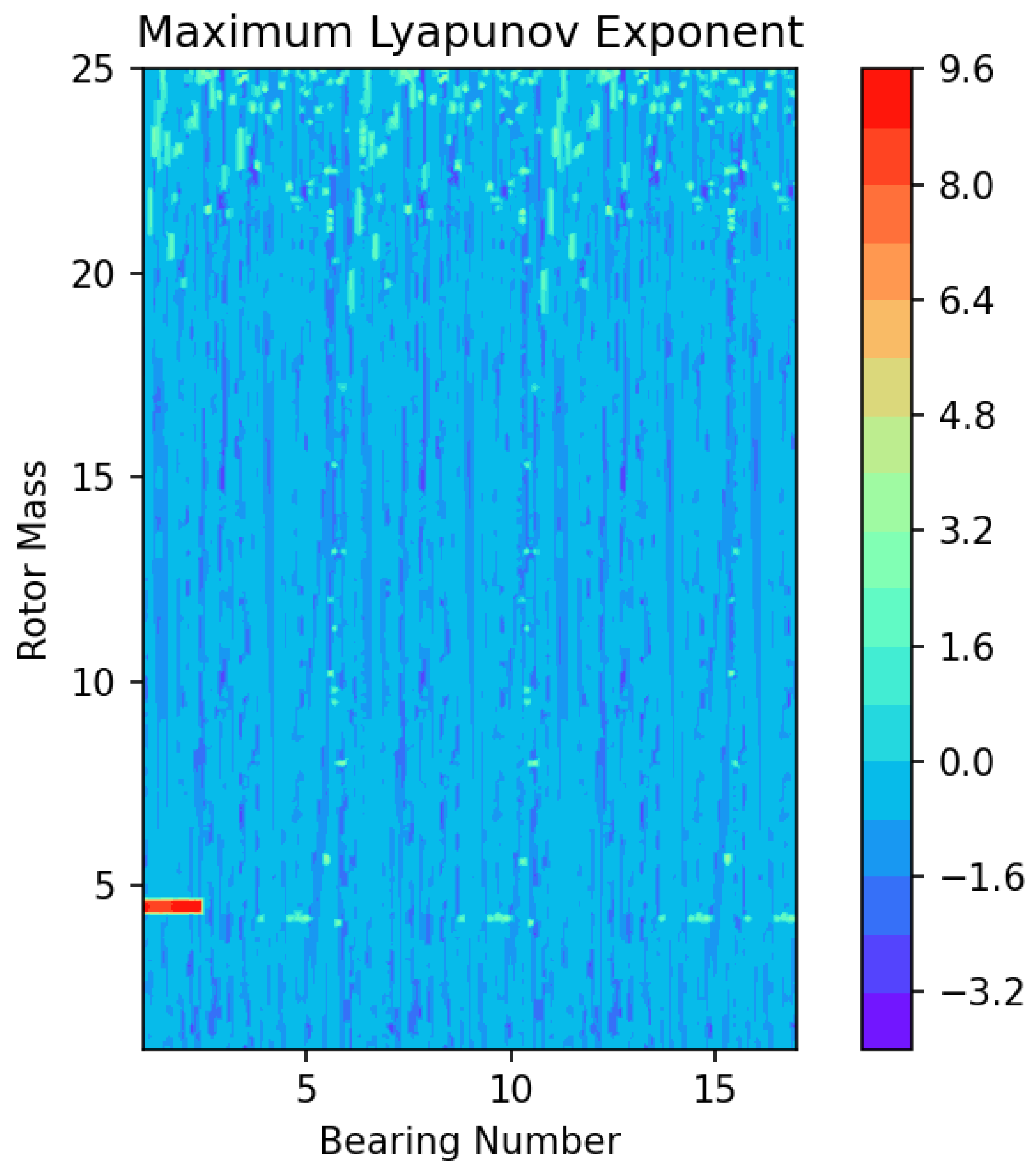
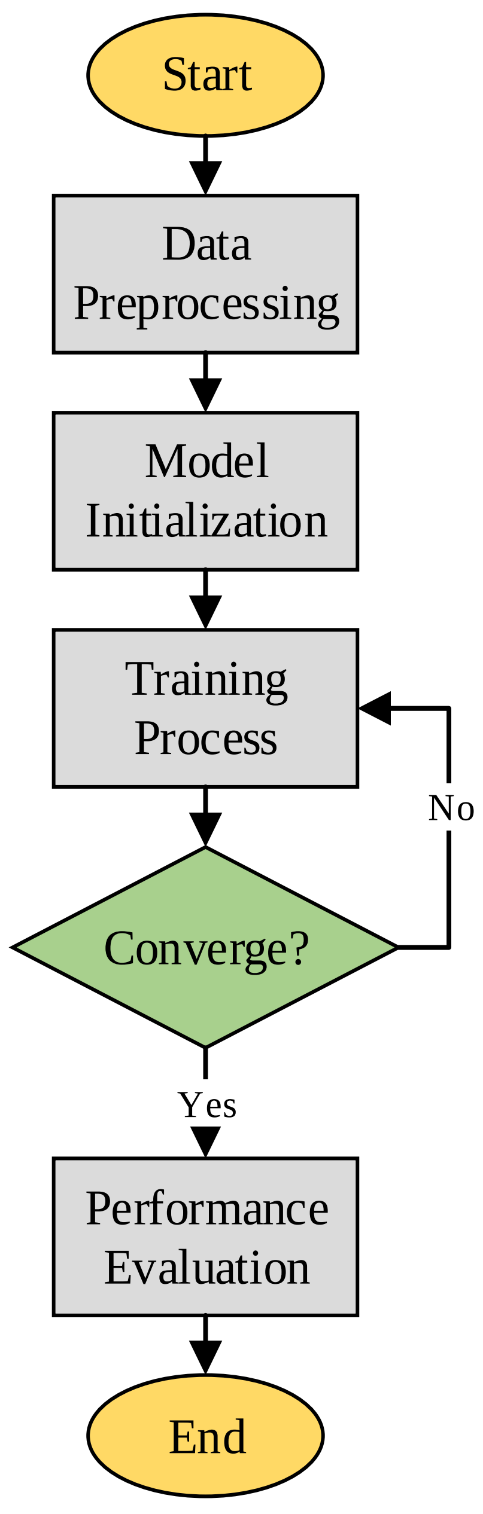


Figure 2. Maximum Lyapunov exponent map.



Start

Data Preprocessing

Model Initialization

Training Process

Converge?

No

Yes

Performance Evaluation

End

Figure 3.Training flowchart of the proposed method.

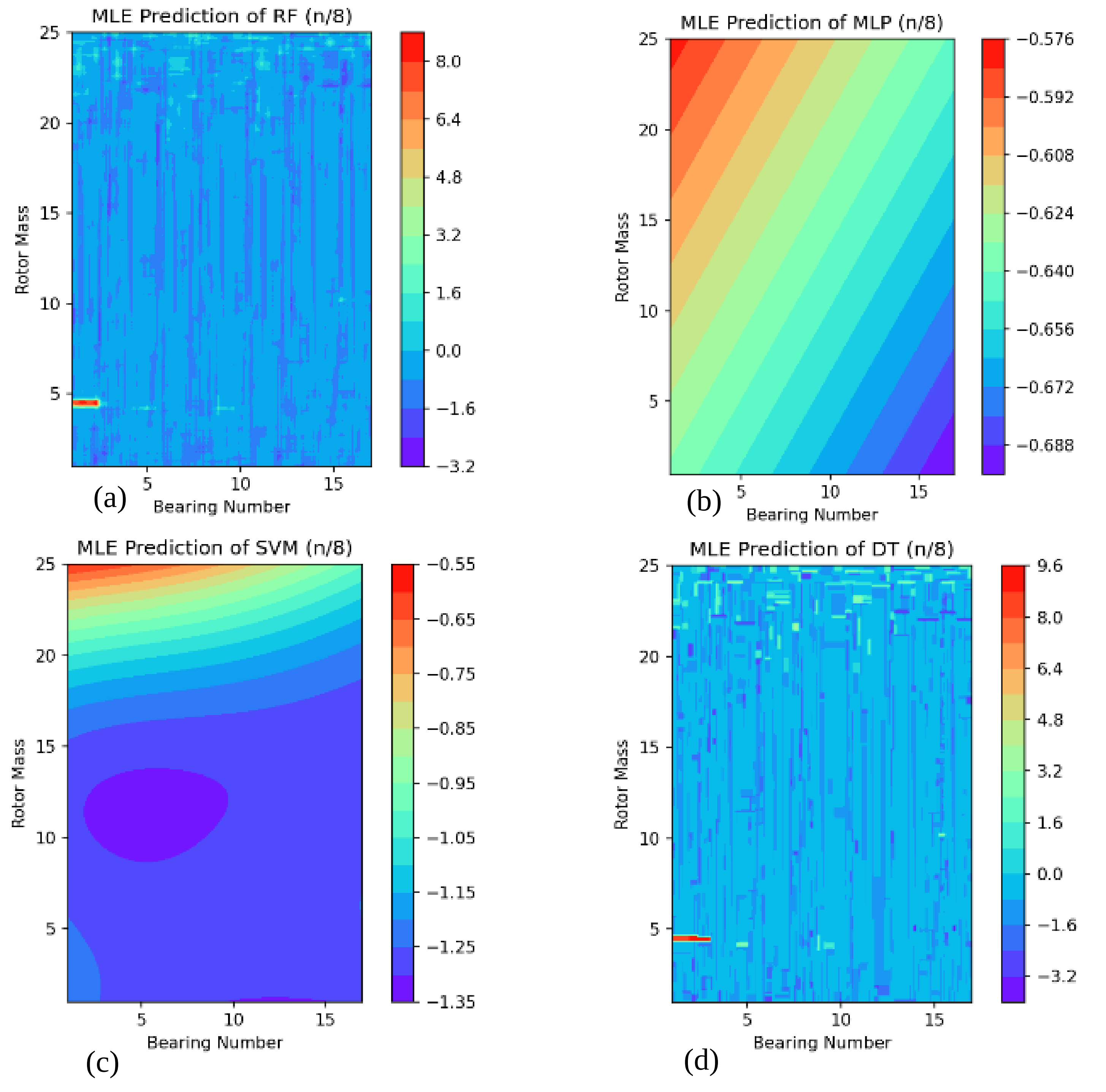


Figure 4. MLE prediction results of (a) RF (b) MLP (c) SVM (d) DT with 1/8 of total training samples.