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航空燃气涡轮转子的非协调进动

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NONSYNCHRONOUS WHIRLS OF THE TURBINE ROTOR IN AEROJET ENGINES

摘要 在研究某两种型号航空发动机振动的过程中,作者曾对数十台发动机的振动信号做过实时数字分析。分析结果表明,其中相当多台在工作转速范围内,存在自动跟踪的精确1/2阶非协调进动,并且这常常是使该发动机振动较大的主要原因。文中介绍了这种非协调进动的表现特征及典型的数字分析结果。 本文对产生非协调进动的原因作了具体分析,初步归结为套齿联轴器中的内摩擦,叶尖间隙的气动弹性,滚珠轴承的非线性刚性,以及后支承非线性刚性等因素。导出了在这些因素联合作用下悬臂式转子运动的四个非线性微分方程。结合具体结构参数,在模拟计算机及数字计算机上作了解算。 研究结果表明:在这些因素的联合作用下,使处于超临界工作状态的悬臂式低压涡轮转子产生自激。由于激起的进动频率接近1/2转速,因分谐波共振,就形成了自动跟踪的精确1/2阶非协调进动。套齿联轴器内的摩擦力矩是首要的自激因素,后支承非对称、非线性刚性则是形成自动跟踪1/2阶分谐波振动的主要原因。 文章还提出了在不改变发动机结构情况下可能采取的排振措施。

关键词:

Abstract: Through full-scale engine vibration investigations in recent years we found that in a number of the engines tested there existed the phenomenon of 1/2 order sub-harmonic vibration（the half-frequency whirl）,which often became the major cause for excessive vibration level in test.This is a phenomenon of non-linear self-excited vibration.If we find out its source and inhibit or eliminate it,the mechanical performance of such a type of engine will certainly be improved.Based on the characteristics of the nonsynchronous whirls as shown in engine vibration spectra and by taking into account the details of construction of the engine,we have analysed four possible major factors of self-excited vibration: the unbalanced torque force caused by circumferential variations of blade tip clearances)the aero-elastic effect of the radial clearances of labyrinth seal)the fric-tional force within the splined coupling)and the non-linear stiffness of the supports.This paper summarizes briefly the 1/2 order sub-harmonic vibration phenomena observed in engine test,and,taking the overhung rotor as the mathematical model,deduces its dynamic equations with considering the effect of the major factors mentioned above.This paper discusses the destabilizing factors in connection with a specific type of aircraft engine,and studies the dynamics of the overhung low-pressure turbine rotor under the combined action of these factors for the purpose of explaining the phenomena observed in the spectra of engine vibrations.Investigations show that the frictional force within the splined coupling is the most important factor of self-excited vibration,and the nonlinear stiffness of the back support is responsible for transforming the self-excited vibration into autotracking 1/2 order sub-harmonic whirl.The results obtained from numerical calculation and simulation on an analoque computer are favourable to explain the various kinds of non-synchronous whirls observed in test.This paper also studies the possibility of improving system stability by modification of labyrinth（comb-type）seal,and