RAPIDLY ROTATING VACUUM PUMP

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ABSTRACT

A rapidly rotating vacuum pump includes a magnet-mounted rotor driven by an electric drive motor with a predetermined constant nominal rotational frequency ($f_{\text{nom}}$). The rotor and a rotor bearing are embodied in such a way that the bending-critical counter-rotational resonance frequency ($f_{\text{res}}$) is between 3% and a maximum of 30% above the nominal rotational frequency ($f_{\text{nom}}$), thereby preventing an overspeed.
RAPIDLY ROTATING VACUUM PUMP

[0001] Rapidly rotating vacuum pumps, i.e. particularly magnetically supported turbomolecular pumps of the non-displacement type, require a reliable overspeed protection since, due to centrifugal forces, rotational speeds in the overspeed range do not only lead to destruction of the vacuum pump but may also cause considerable danger to persons.

[0002] In practice, overspeed protection of rapidly rotating vacuum pumps is effected by use of complex electronic assemblies which are operative to monitor the rotational speed of the rotor and respectively of the electric drive motor, and to delimit the rotational speed by electronic means. Although it is in this manner possible, by high technical expenditure and redundant hard- and software, to realize a safe active overspeed protection for rapidly rotating vacuum pumps, the resultant high technical expenditure will cause considerable costs.

[0003] It is an object of the invention to provide a rapidly rotating vacuum pump which is equipped with a simple and reliable overspeed protection.

[0004] According to the invention, the above object is achieved by the features of claim 1.

[0005] In the rapidly rotating vacuum pump of the invention, the rotor is designed to the effect that its bending-critical counter-rotational resonance frequency is between 3% and a maximum of 50% above the nominal rotational frequency. There is provided no active overspeed protection, i.e. no direct controlling and limiting of the rotational speed which would exist in addition to the control means for the electric drive motor.

[0006] The process of setting the bending-critical counter-rotational resonance frequency to a frequency between 3% and a maximum of 50% above the nominal rotational frequency can be performed in various manners. Particularly the mass, the geometry and the support of the rotor of the vacuum pump can be changed and adapted in such a manner that the bending-critical counter-rotational resonance frequency will be maximally 50% above the nominal rotational frequency, thus immanently preventing an overspeed. The resonance vibrations at the bending-critical counter-rotational resonance frequency will consume considerable power so that a run-up to a rotational frequency at a level thereabove would be possible only with a massive power reserve. The drive power of the electric drive motor has to be set in a manner allowing it to be completely consumed by the resonance vibrations at a rotational frequency in the range of the bending-critical counter-rotational resonance frequency. Thus, there is created an immanent overspeed protection by means of hardware, wherein failure is virtually excluded. The expenditure for an active overspeed protection can be omitted, allowing for a considerable reduction of the costs for overspeed protection.

[0007] In contrast to rigid-body-critical resonance frequencies, which are relatively low and normally can be passed through quickly and with relatively little power reserve, the bending-critical frequencies are situated on relatively high frequency levels. For this reason, the bending-critical counter-rotational resonance frequency is especially suited to be utilized for immanent overspeed protection.

[0008] The rotor of the vacuum pump is supported by a magnetic bearing. A magnetic bearing is to be understood herein as a magnetic bearing with respect to at least one radial degree of freedom. In practice, however, the rotor of a rapidly rotating vacuum pump is magnetically supported with respect to all five degrees of freedom if a magnetic bearing is provided. During operation, the magnetic bearing itself will generate radial vibrations of the rotor due to the counterbalancing control. Thereby, particularly also bending-critical vibrations are activated, and it will not be possible for the pump to pass through these vibrations as long as no suitable magnetic-support control algorithm is provided for passing through the bending-critical resonance frequencies. Such a suitable control algorithm is not provided herein. Instead, the magnetic-support control algorithm is configured to the effect that, on the basis of the available drive energy, the pump cannot pass through the bending-critical resonance frequencies.

[0009] Preferably, the bending-critical counter-rotational resonance frequency is between 5% and 25% of the nominal rotational frequency, and more preferably it is in the range of 20% above the nominal rotational frequency. An interval of about 20% above the nominal rotational frequency will offer sufficient safety from overshoot beyond the rotational frequency in the process of running up the rotor from standstill to the nominal rotational frequency. During run-up, it can thus be avoided that said overshoot will undesirably cause the occurrence of bending-critical counter-rotational resonance frequencies. On the other hand, the bending-critical counter-rotational resonance frequency should be as closely as possible above the nominal rotational frequency, thus obviating the requirement of a rotor design having an unnecessary extent of stability.

[0010] Preferably, the rapidly rotating vacuum pump is a vacuum pump of the non-displacement type, e.g. a turbomolecular vacuum pump. In turbomolecular vacuum pumps, the rotational speeds are usually in the range from 10,000 to 100,000 r/min. Rotational speeds and respectively rotational frequencies in such a high range make it especially advisable to use a magnetic bearing for supporting the rotor.

[0011] The invention will be explained in greater detail hereunder with reference to the FIGURE.

[0012] The FIGURE shows a so-called Campbell diagram for a rapidly rotating vacuum pump.

[0013] In the Campbell diagram presented in the FIGURE, the resonance frequency $f_{\text{res}}$ of the rotor is plotted over the rotational frequency $f_{\text{rot}}$ of the rotor.

[0014] The rapidly rotating vacuum pump herein is a turbomolecular vacuum pump whose rotor is supported completely in a five-axial arrangement by means of a magnetic bearing. The rotor is driven by an electric drive motor and is operated at a constant predetermined nominal rotational frequency $f_{\text{nom}}$.

[0015] Represented in the diagram are, first, in a lower range of rotational speeds, respectively two by two rigid-body-critical resonance frequency curves $f_{\text{res}}$, $f_{\text{res}}$, $f_{\text{res}}$, and $f_{\text{res}}$. These resonance frequencies will change to a relatively slight extent along with the rotational frequency $f_{\text{rot}}$ of the rotor. Further shown are, in a higher range of rotational speeds, a curve $f_{\text{rot}}$ representing the bending-critical counter-rotational resonance frequency and a curve $f_{\text{rot}}$ representing the bending-critical co-rotational resonance frequency. Further, represented in an interrupted line, the so-called position vector $f_{\text{rot}}$ is shown. At the point where the position vector $f_{\text{rot}}$ intersects the bending-critical counter-rotational resonance frequency curve $f_{\text{res}}$, the bending-critical counter-rotational resonance frequency $f_{\text{res}}$ for the present vacuum pump can be read out.
In the present example, the bending-critical counter-rotational resonance frequency $f_{cr}$ for the rotor of the vacuum pump is substantially 970 Hz. The nominal rotational frequency $f_{nom}$ of the vacuum pump and respectively of the drive motor, the drive motor control unit and the rotor is substantially 800 Hz. Thus, the bending-critical counter-rotational resonance frequency $f_{cr}$ is substantially 21% above the nominal rotational frequency $f_{nom}$ of the vacuum pump.

The drive power of the electric motor is limited in such a manner that it will be completely consumed by the counter-rotational resonance frequencies in case that the rotational frequency of the rotor should happen to reach the bending-critical counter-rotational resonance frequency $f_{cr}$.

The vacuum pump does not comprise any further active overspeed protection, i.e. it does not comprise a second rotational-speed control loop provided in addition to the rotational-speed control loop of the motor control.

The curve 16 representing the bending-critical counter-rotational resonance frequency cannot be influenced by a corresponding setting of the control parameters of the magnetic bearing of the vacuum pump. However, the control parameters of the magnetic bearing are provided to the effect that the bending-critical resonance frequencies will be activated strongly enough to exclude that an operation with the drive energy available would allow the pump to pass through the bending-critical resonance frequencies. For this purpose, the control parameters for the magnetic bearings should be relatively soft.

1. A rapidly rotating vacuum pump, comprising a rotor driven by an electric drive motor and having a predetermined constant nominal rotational frequency, wherein said rotor is supported by a magnetic bearing, a bending-critical counter-rotational resonance frequency of the rotor is between 3% and a maximum of 30% above the predetermined nominal rotational frequency, and no active overspeed protection is provided.

2. The rapidly rotating vacuum pump according to claim 1, wherein said vacuum pump is a non-displacing vacuum pump.

3. The rapidly rotating vacuum pump according to claim 2, wherein said vacuum pump is a turbomolecular pump.

4. The rapidly rotating vacuum pump according to claim 3, wherein the bending-critical counter-rotational resonance frequency is between 5% and 25% of the predetermined nominal rotational frequency.

5. A vacuum pump having a rotor, a stator, magnetic bearings, and a drive motor which accelerates the rotor to and rotates the rotor at a preselected nominal rotational frequency of at least 10,000 rpm, the rotor comprising:

   a mass and geometry which defines a bending-critical counter-rotational resonance frequency which is at least 3% greater than the predetermined nominal rotation frequency, such that the rotor is constrained to rotate at speeds below its bending-critical counter-rotational resonance frequency.

6. The vacuum pump according to claim 5, wherein the binding-critical counter-rotational resonance frequency is less than 30% greater than the preselected nominal rotational frequency.

7. The vacuum pump according to claim 5, wherein the drive motor and the magnetic bearings are free of electronic active overspeed protection.

8. A method of designing a vacuum pump including designing a rotor and a rotor bearing such that a bending-critical counter-rotational resonance frequency is between 3% and 30% greater than a nominal rotational frequency.

9. A rotor made by the method according to claim 8.

10. A vacuum pump made by the method of claim 8.