ISO 1940 G2.5 GRADE BALANCING FOR ELECTRIC VEHICLE MOTOR

FIELD OF INVENTION

[0001] The present disclosure generally relates to automobile industry, and to ISO 1940 G2.5 Grade Balancing for electric vehicle (EV) Motor, specifically relates to rotor balancing system for dynamically balancing rotors in electric vehicle (EV) Motors.

BACKGROUND

[0002] The subject matter discussed in the background section should not be assumed to be prior art merely as a result of its mention in the background section. Similarly, a problem mentioned in the background section or associated with the subject matter of the background section should not be assumed to have been previously recognized in the prior art. The subject matter in the background section merely represents different approaches, which in and of themselves may also correspond to implementations of the claimed technology.

[0003] Electric vehicles are becoming an increasingly popular segment of the automobile industry across the world. Some of the benefits accrued by users of electric vehicles include the low running cost, ease of maintenance, storage space, and low noise. In addition to the benefits provided to the users, electric vehicles are also environment-friendly as they do not contribute to carbon emission.

[0004] Due to the increasing popularity of electric vehicles, there is an increasing need to optimize the performance of such vehicles. One such aspect of electric vehicles that significantly impact its performance, and requires improvement is the electric motor of such vehicles. Due to the unbalanced motor of electric vehicles, the whirling effect of rotor increases causing noises in the motor of the electric vehicle resulting in bad Noise Vibrations and Harshness (NVH) characteristics of the electric vehicle.

[0005] In rotor assemblies for electric vehicles, centrifugal force is proportional to the square of the angular velocity. Consequently, at high speeds, these forces become significantly large, which can increase contact loads, alter contact angles (thereby changing bearing stiffness), and generate additional friction heat due to sliding. An unbalanced load exacerbates

these issues, leading to increased NVH issues. Thus, rotor balancing becomes a crucial process to manage these forces effectively and to maintain the structural integrity and efficiency of the motor.

[0006] Therefore, there is a pressing need for developing a balanced motor for electric vehicles that not only ensures smooth rotor operation but also significantly improves the NVH characteristics. This development will enhance the overall performance and reliability of electric vehicles, making them more appealing and sustainable for broader adoption.

OBJECT OF THE INVENTION

[0007] An object of the disclosure is to balance the motor of the electric vehicle by 2 plane balancing technique based on ISO 1940 G2.5 Standard.

[0008] Another objective of the disclosure is to estimate the permissible unbalance of the electric motor due to manufacturing constraints for a service speed.

[0009] Yet another objective of the disclosure is to remove required material from the rotor end plates to make the motor balanced.

[0010] Another objective of this invention is to enhance the safety and reliability of electric vehicle motors by utilizing an advanced analysis module capable of determining critical speeds and resonance frequencies.

[0011] A further objective of the invention is to dynamically adjust the amount of material removed from the rotor based on real-time data obtained from operational feedback.

[0012] An additional objective of this invention is to provide a rotor balancing system that incorporates a simulation module for predicting the impact of unbalance on rotor dynamics and operational efficiency.

SUMMARY OF THE INVENTION

[0013] The summary is provided to introduce aspects related to rotor balancing system for electric vehicle motors. This summary is not intended to identify essential features of the

claimed subject matter nor is it intended for use in determining or limiting the scope of the claimed subject matter.

[0014] In a preferred embodiment, the present invention provides an electric vehicle motor balancing system comprising: a rotor divided into two parts of length L_a and L_b and at each part of the rotor includes end plates from which material is removable to adjust rotor balance, a calculation unit configured to determine a permissible residual specific unbalance for the rotor based on a service speed and a balance quality grade according to ISO 1940 G2.5 standards, an interface configured to display the permissible residual specific unbalance and to receive input parameters including the service speed and the balance quality grade, a balancing unit configured to remove material from the end plates of the rotor as directed by the calculation unit based on the input parameters, a simulation module for simulating rotor dynamics to assess changes in rotor balance from material removal, and an analysis module for determining critical speeds of the rotor and for monitoring unbalance responses based on operational data of the rotor. The balancing unit is configured to adjust the material removal based on feedback from the simulation module and the analysis module, to ensure the rotor maintains an optimal balance under varying operational conditions.

[0015] In another embodiment, the rotor is configured to operate the service speed (110); and wherein the rotor comprises magnetic materials selected from the group consisting of cobalt, nickel, iron, and combinations thereof

[0016] In an embodiment, the balancing unit includes a precision material removal tool configured to remove material at specified radii on the rotor end plates, the specified radii being determined based on the calculated permissible residual specific unbalance.

[0017] In a further embodiment, the simulation module is configured to model the rotor and motor housing as flexible bodies to accurately capture mass and stiffness characteristics, and to evaluate changes in rotor dynamic behavior due to material removal.

[0018] In another aspect, the analysis module includes a critical speed analysis function configured to determine the impact of changes in support stiffness versus shaft stiffness on the rotor's critical speeds. The analysis module includes an unbalance response function configured to detect critical resonance frequencies and corresponding RPMs caused by the

rotor's unbalanced mass. The interface is configured to allow manual adjustment of the service speed and balance quality grade to simulate different rotor balancing scenarios. The interface provides visual feedback of the rotor's unbalance state before and after material removal based on the simulation results. The balancing unit is configured to dynamically adjust the amount of material to be removed in response to feedback from the simulation module regarding rotor balance. The interface includes controls for the user to initiate and stop the material removal process based on real-time simulation data.

[0019] Other aspects and advantages of the invention will become apparent from the following description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The accompanying drawings constitute a part of the description and are used to provide further understanding of the present disclosure. The drawings illustrate exemplary embodiments of the present disclosure and, together with the description, serve to explain the principles of the present disclosure.

[0021] **Fig. 1A** illustrates an exemplary unbalanced rotor of an electric motor, in accordance with an embodiment of the present disclosure.

[0022] **Fig. 1B** illustrates a graph of permissible residual specific unbalance based on balance quality grade (G) and service speed (n), in accordance with an embodiment of the present disclosure.

[0023] **Fig. 1C** illustrates an exemplary table of rotor unbalance calculation, in accordance with an embodiment of the present disclosure.

[0024] **Fig. 2A** illustrates an exemplary balancing of the rotor of the electric motor, in accordance with an embodiment of the present disclosure.

[0025] **Fig. 2B** illustrates an exemplary graph of the balanced rotor characteristics of the electric motor, in accordance with an embodiment of the present disclosure.

[0026] **Fig. 3A-3C** illustrates stimulation setup illustrating the flexible body modeling of the rotor and motor housing, in accordance with an embodiment of the present disclosure.

[0027] **Fig. 4A-4B** illustrates an exemplary graph of motor bearing forces based on G2.5 ISO 1940 unbalance at the rotor center plane, in accordance with an embodiment of the present disclosure

[0028] **Fig. 5** illustrates rotor shaft mode analysis depicting critical frequency of 378 Hz, in accordance with an embodiment of the present disclosure

[0029] **Fig. 6** illustrates graphical representation of damped natural frequency analysis, depicting critical speed conditions under varying support and shaft stiffness, in accordance with an embodiment of the present disclosure

[0030] **Fig. 7** illustrates graphical representation of critical speed analysis comparing mode shapes with bearing stiffness variations, in accordance with an embodiment of the present disclosure

[0031] **Fig. 8A-8D** illustrates graphical representation of unbalance study, showing critical resonance frequency/RPM caused by the rotor's unbalanced mass, in accordance with an embodiment of the present disclosure.

[0032] **Fig. 9** illustrates architecture of the system for implementation, in accordance with an embodiment of the present invention.

[0033] **Fig. 10A** illustrates rotor end plate at unbalanced state, in accordance with an embodiment of the present invention.

[0034] **Fig. 10B** illustrates rotor end plate at balanced state, in accordance with an embodiment of the present invention.

[0035] **Fig. 10C** illustrates dynamic unbalanced load modeling as per ISO 1940 G2.5

DESCRIPTION OF THE INVENTION

[0036] The description set forth below in connection with the appended drawings is intended as a description of various embodiments of the present disclosure and is not intended to represent the only embodiments in which the present disclosure may be practiced. Each embodiment described in this disclosure is provided merely as an example or illustration of the present disclosure, and should not necessarily be construed as preferred or advantageous over other embodiments. The description includes specific details for the purpose of providing a thorough understanding of the present disclosure. However, it will be apparent to those skilled in the art that the present disclosure may be practiced without these specific details.

[0037] Electric automobiles have been growing in popularity and demand due to the several benefits and advantages offered by such vehicles. However, optimization of performance of electric vehicles have been a persistent issue due to the motor unbalancing in such vehicles. Hence optimization of performance of such vehicles, especially with regard to the noises and reliability of such vehicles, is only possible with proper and even weight distribution of the rotor in the electric motor. The balancing of the motor of the electric vehicles can be achieved by removing the required extra weight from the rotor from the desired locations, so as to evenly distribute the weight of the rotor.

[0038] The motor of a vehicle powers the electric vehicle by producing torque, by the action of the rotation of the rotor. Due to manufacturing defects, the weight of the rotor may not be evenly distributed. The unbalanced rotor may cause motor to produce unwanted vibrations and can also significantly decrease the performance of the electric vehicle. Additionally, vibrations from the unbalanced rotor creates excessive noise and resonance, that ultimately compromise the structural integrity of the electric motor that supports the rotor assembly. The damage caused by unbalance rotor is especially apparent in bearings, suspension equipment, support housing, and the equipment foundation.

[0039] The structural component of electric vehicle such as the rotor is conventionally made from materials like steel and cast iron in the automotive industry. In existing technologies, the unbalance of the rotor is mitigated by adding weight to the rotor so as to make the rotor evenly distribute by trial runs and 1 or 2 plane balancing. As, different electric vehicles requires

especially designed motors to cater the need of power of each electric vehicle. The balancing of rotor depends on two factors such that the ratio of the length of the rotor (L) to the diameter of the rotor (D) and the operating speed of the rotor.

[0040] The present disclosure relates to ISO 1940 G2.5 grade balancing for electric motor. The present disclosure comprises removing required weight from the rotor by ISO 1940 G2.5 grade 2 plane balancing.

[0041] **Fig. 1A** illustrates an exemplary unbalanced rotor of an electric motor, in accordance with an embodiment of the present disclosure. The rotor **102** having a length L may be made of, but not limited to, cobalt, nickel, iron, or any other strong magnetic material, as the electric motor works on the principle of law of electromagnetic induction. Thus, the rotor must be made up of magnetic material in order to generate torque by the action of magnetic field generated in the motor. The rotor **102** is divided into two parts of length L_a **104** and L_b **106**.

[0042] **Fig. 1B** illustrates a graph of permissible residual specific unbalance based on balance quality grade (G) and service speed (n), in accordance with an embodiment of the present disclosure. The graph **108** represents the Permissible residual specific unbalance of the rotor **102** corresponding to the service speed (n) of the rotor **110** represented on the x-axis of the graph **108** and the plurality quality grade (G) **112** represented as the slope lines in the graph **108**. Additionally, the desired permissible residual specific unbalance of the rotor **102** may be deduced by the graph **108** by looking up to the y-axis **114** corresponding to the rated service speed (n) **110** of the rotor **102** and the desired quality grade (G) **112.** By way of an example, let's say the rotor **102** is designed to operate at a service speed (n) of 2500rpm and quality grade (G) is 2.5 then the corresponding value on the y-axis **114** of the graph **108** denotes the permissible residual specific unbalance that is 9.55gmm/kg.

[0043] **Fig. 1C** illustrates an exemplary table of rotor unbalance calculation, in accordance with an embodiment of the present disclosure. The table **116** comprises a rotor data, a permissible residual balance, an allocation to tolerance plane, a check on limitation, and mass and distance of material to be removed from the rotor. The rotor data is already known in the manufacturing process comprising, a rotor mass, a rotor length, a service speed of the rotor and a grade quality (G) of the rotor. Further, the permissible residual balance of the rotor may be deduced by the graph **108** as explained in detail in **Fig. 1B.** The allocation to tolerance plane

may be calculated for the rotor based on the permissible residual balance of the rotor and the length of the rotor. Further, the limitations may be checked for the rotor and the mass and distance of the removal of the required weight of rotor is calculated.

[0044] **Fig. 2A** illustrates an exemplary balancing of the rotor of the electric motor, in accordance with an embodiment of the present disclosure. The rotor **202** may be analogous to the rotor **102** of the **Fig. 1A.** The rotor **202** may be balanced by removing the required material from the desired location of the rotor **202**, by the use of the rotor unbalance calculation table **116** as explained in detail in **Fig. 1C**. By way of an example, a mass of 371.1276mg of material is removed from the rotor **202** at the radius of 42mm based on the results derived in the table **116.**

[0045] **Fig. 2B** illustrates an exemplary graph of the balanced rotor characteristics of the electric motor, in accordance with an embodiment of the present disclosure. The graph **204** represents the balanced motor characteristics based on the acceleration, shaft or rotor speed, and the force generated by the electric motor. The graph **204** denoted that the acceleration and the force generated by the said motor peaked at the rotor speed of around 10000 RPM.

[0046] Hence the techniques to balance the motor of the electric vehicle in the present disclosure balances the weight of the rotor such that that the weight of the rotor is evenly distributed and do not vibrate or make loud noise when in operation.

[0047] Fig. 3 illustrates stimulation setup illustrating the flexible body modeling of the rotor and motor housing, in accordance with an embodiment of the present disclosure. In **Fig. 3a**, A rotor assembly is depicted and presents a detailed view of the rotor assembly used in the electric vehicle motor balancing system. The rotor is shown in a pre-balancing state, highlighting specific areas where material removal will be critical for achieving desired balance. The rotor includes segments, each marked for potential unbalance correction, where precision material removal tools can target based on the calculated unbalance data from the system's analysis module. In **Fig. 3b**, illustrates rotor (302) with material removal points. Fig. 3b elaborates on the rotor after the initial material removal process. It depicts specific points on the rotor's end plates where material has been removed, enhancing balance according to the permissible residual specific unbalance values calculated by the electric vehicle motor balancing system.

Each point is quantified with respect to the amount of material removed, directly linking to the simulation data that predicts the impact on rotor dynamics and efficiency.

[0048] **Fig. 3c** illustrates assembled rotor (302) in motor housing (304). In an embodiment as shown in this figure, the rotor (302) fully assembled within the motor housing (304), post-adjustment is displayed. It provides an overview of the rotor's alignment and setup within the motor, emphasizing the improved structural integrity and reduced vibration due to the balancing adjustments. As depicted in Fig. 3c, the balancing unit dynamically adjusts the rotor (302) balance in response to real-time feedback from operational data.

[0049] **Fig. 4** illustrates an exemplary graph of motor bearing forces based on G2.5 ISO 1940 unbalance at the rotor center plane, in accordance with an embodiment of the present disclosure. **Fig. 4a** illustrates bearing forces at normal load. Figure 4a shows a graphical representation detailing the bearing forces on the rotor under normal operating conditions. The graph illustrates how the forces are distributed across the rotor's bearings before the balancing adjustments, serving as a baseline for comparison with post-adjustment data. Contrasting to Figure 4a, In **Fig. 4b,** illustrates bearing forces at maximum load. Figure 4b provides data on bearing forces under maximum load conditions post-balancing. It demonstrates the system's effectiveness in redistributing forces more evenly across the bearings, thus reducing potential wear and extending the bearing life.

[0050] **Fig. 5** illustrates rotor shaft mode analysis depicting critical frequency of 378 Hz, in accordance with an embodiment of the present disclosure. In Fig. 5, the analysis is identified through the stimulation studies as the frequency where resonance might occur if not properly managed. The mode shape graphically represents the deformation pattern of the rotor, highlighting areas of maximum amplitude displacement due to vibrational forces. Fig. 5 depicts at Y-axis the amplitude of displacement or deformation of the rotor. In x-axis, represents to the rotor length, from one end to the other, allowing viewers to see where along the rotor the maximum deformations occur. In Fig. 5, at the peak points identify the specific locations along the rotor where deformation peaks, indicative of potential weak points or areas susceptible to resonance. In fig. 5, the mode shape of the rotor at a critical operational frequency identified through the system's simulation module. It graphically represents the deformation pattern of the rotor at critical frequency, highlighting the areas of maximum stress and the alterations made to the mode shape to avoid resonance.

[0051] **Fig. 6** illustrates graphical representation of damped natural frequency analysis, depicting critical speed conditions under varying support and shaft stiffness, in accordance with an embodiment of the present disclosure. In this Fig. 6, depicts the damped natural frequencies of the rotor against various operational speeds. The graphical representation shown for identifying potential resonance peaks and for illustrating the effectiveness of the balancing system in adjusting to dynamic conditions. At Y-axis, the present disclosure shows the natural frequencies of the rotor in Hz, representing the frequencies at which the rotor naturally tends to vibrate due to its physical and material properties. At X-axis, the present disclosure represents the rotor's operational speeds, typically in RPM (Revolutions Per Minute), showing a range from idle to maximum operational speeds. A line or curve, as shown in this figure, will indicate how the natural frequencies shift with changes in speed, highlighting critical points where the operational speed coincides with a natural frequency, potentially leading to resonance. The present disclosure shows when the rotor's operational speed intersects with its natural frequencies. For example, if a line crosses the Y-axis at 378 Hz at an operational speed of 22500 RPM, it indicates a critical resonance point. In an embodiment, the rotor balance shift in the frequencies away from critical operational speeds as a result of the balancing interventions. For example, when the rotor is rotating in half speed resonance will happen at 40500 rpm for the mode 1 (378Hz). In addition, when the rotor is rotating in double the speed the resonance will happen at 11500 rpm for the mode 1 (378 Hz). This figure demonstrates how the balancing system of the present disclosure effectively shifts natural frequencies away from dangerous resonance zones. Figure 6 shows how the rotor responds to different damping scenarios, illustrating the system's capability to maintain stability and efficiency under diverse conditions.

[0052] **Fig. 7** illustrates graphical representation of critical speed analysis comparing mode shapes with bearing stiffness variations, in accordance with an embodiment of the present disclosure. At Y-axis, the present disclosure represents critical speeds of the rotor, shown in RPM (Revolutions Per Minute), indicating at which speeds the rotor is likely to encounter resonance conditions. At X-axis, the present disclosure represents the bearing stiffness, typically measured in Newtons per millimeter (N/mm), which affects the critical speeds by altering the system's dynamic response. The line or curve in the fig. 7 shows the relationship between bearing stiffness and critical speeds. Points where the curve peaks or troughs are particularly significant as they indicate potential resonance speeds. **In fig. 7,** shows a peak at 8500 N/mm leading to a critical frequency of 378 Hz, this points to a potential risk area and

depicts critical speeds against bearing stiffness to determine safe operating limits for the rotor. When the bearing stiffness reaches nearby 8500 (N/mm) the natural frequency of the rotor shaft is 378Hz, 2000Hz and 6000Hz respectively for mode 1, mode 2 and mode 3. It visually supports the analysis module's functionality in determining the impact of changes in support stiffness versus shaft stiffness on the rotor's critical speeds.

[0053] **Fig. 8** illustrates graphical representation of unbalance study, showing critical resonance frequency/RPM caused by the rotor's unbalanced mass, in accordance with an embodiment of the present disclosure. In **Figs. 8a to 8d,** shows unbalance Response Analysis and in Y-axis shows the magnitude of unbalance or the phase shift (in degrees), indicating the severity and nature of the unbalance at various operational points. At x-axis shows the rotor speed in RPM, aligning the unbalance data with the rotor's operational speed to show how unbalance changes with speed variations. The curves, at each figs. 8a-8d, depict how unbalance magnitudes and phase shifts vary with speed, highlighting critical points where adjustments are most needed. **Fig. 8a** illustrates unbalance magnitude at operational speeds. Particularly, Fig. 8a depicts how the magnitude of unbalance varies across a range of operational speeds, identifying speeds at which unbalance peaks, suggesting areas where balancing adjustments are critical. **Fig. 8b** illustrates phase shift analysis at varying speeds. In Fig. 8b, the phase shifts in unbalance across different speeds, providing insights into how the dynamic characteristics of the rotor change with speed and how these changes are managed. **In Fig. 8c** illustrates detailed unbalance response at specific speed. In Fig. 8c, focuses at a specific operational speed, providing detailed views of both unbalance magnitude and phase shift, offering a deep dive into the rotor's behavior at this particular operational point. **Fig. 8d** illustrates comparative analysis on unbalance responses before and after balancing adjustments at multiple speeds, demonstrating the effectiveness of the balancing system in real-time adjustments and corrections.

[0054] In Figs. 8a-8d, depicts the detailed unbalance response of the rotor in both the X and Y directions across various speeds. They show how the system's unbalance response function detects and adjusts to changes in rotor unbalance, ensuring optimal balance is maintained. Each graph provides a different perspective on the rotor's dynamic response to unbalance, highlighting the precision and responsiveness of the balancing system.

[0055] **Fig. 9** illustrates general architecture of the system **900** for implementation, in accordance with an embodiment of the present disclosure. As illustrated, an electric vehicle motor balancing system **900** comprising a rotor **902**, a calculation unit **904**, an interface **906**, a balancing unit **908**, a simulation module **910**, and an analysis module **912**. The rotor **902** is the rotating component of the motor which is balanced using a two-plane technique. In the illustrated embodiment, the rotor is divided into two parts of length La **104** and Lb **106** and at each part of the rotor **902** includes end plates from which material is removable to adjust rotor balance. The rotor **902** is designed to operate at a designated service speed **110** and it comprises magnetic materials (for example, cobalt, nickel, iron, or combinations thereof) to realize the required electromagnetic properties. The system **900** operates by first determining the allowable imbalance in the rotor **902** at the service speed according to the chosen balance quality grade (e.g., ISO 1940 G2.5). The interface **906** is a user-facing module that allows an operator to input key parameters such as the desired service speed and balance quality grade. The interface **906** is configured to receive input parameters including the service speed and the balance quality grade, and to display the permissible residual specific unbalance for the rotor based on those inputs. In this manner, the operator can set the target balance quality (for instance, G2.5) and immediately see the calculated permissible residual specific unbalance that the rotor **902** should achieve for that speed and grade. The calculation unit **904** is operatively connected to the interface and processes the input parameters to determine a permissible residual specific unbalance for the rotor **902** based on the service speed **110** and the balance quality grade according to the ISO 1940 G2.5 standard.

[0056] In an embodiment of the present disclosure, the calculation unit **904** may use standard formulas and lookup data as depicted in Fig. 1b and Fig. 1c of the present disclosure to compute the maximum allowable imbalance mass or eccentricity. The calculated permissible unbalance value is then used to guide the balancing operation, ensuring that the rotor's imbalance is reduced to or below this threshold. Once the permissible residual unbalance is known, the system initiates the active balancing process. The balancing unit **908** is configured to remove material from the rotor's end plates in order to reduce the rotor's imbalance to the permissible value. In one implementation, the rotor's two end plates correspond to two correction planes (at lengths La **104** and Lb **106**) for two-plane balancing. The balancing unit **908** may include or control a precision machining or drilling tool that physically removes a small amount of material from specific locations on the rotor's end plates to counteract the measured imbalance. Notably, the balancing unit **908** includes a precision material removal

tool configured to remove material at specified radii on the rotor end plates, the specified radii being determined based on the calculated permissible residual specific unbalance.

[0057] The calculation unit **904** determines how much mass should be removed and at what radial distance on each end plate to effectively compensate for the uneven mass distribution. The balancing unit **908** receives these directives from the calculation unit **904** and is configured to remove material from the end plates of the rotor **902** as directed by the calculation unit **904** based on the input parameters. During operation, the balancing unit **908** acts in real-time to gradually trim the rotor's mass distribution. As illustrated in Fig. 9, the calculation unit **904** and the balancing unit **908** determines the amount and location of material to remove from the rotor **902**. As material is removed, the rotor's mass imbalance reduces, moving the rotor **902** toward a balanced state. The balancing unit **908** to the rotor **902** as depicted in Fig. 9 indicates this action of material removal being applied to the rotor **902**. After an initial removal operation, the rotor's imbalance is markedly reduced; at this point, the system can verify whether the rotor **902** now falls within the permissible unbalance limits or if further correction is necessary. To assess the effect of the material removal and to ensure that the rotor **902** is properly balanced under operational conditions, the system **900** employs the simulation module **910** and the analysis module **912** in a feedback loop. The simulation module **910** is configured to simulate the rotor dynamics to assess changes in rotor balance from the material removal.

[0058] In the embodiment of the present disclosure, once the balancing unit **908** has removed some material, the updated rotor properties (mass distribution, moments of inertia, etc.) are fed into the simulation module **910** for analysis. The simulation module **910** preferably models the rotor **902** and the motor housing as flexible bodies to accurately capture mass and stiffness characteristics, and evaluates changes in the rotor's dynamic behavior due to the material removal. The simulation yields information such as the new imbalance magnitude, the rotor's response at various speeds, and any shifts in its natural frequencies or mode shapes as a result of the balancing correction. This simulated data is crucial for anticipating how the rotor will perform at the service speed **110** and across the operating range without having to physically run the motor at full speed for each iteration. In parallel, the analysis module **912** processes data to ensure the rotor's dynamic performance is optimal. The analysis module **912** includes specialized analytical functions, in particular, it has a critical speed analysis function configured to determine the impact of changes in support stiffness versus shaft stiffness on the rotor's critical speeds. The analysis module **912** further comprises an unbalance response

function configured to detect critical resonance frequencies and corresponding RPMs caused by the rotor's unbalanced mass. This function analyzes the rotor's vibration response (either from simulation or actual sensors) to identify any resonant peaks that indicate the presence of residual unbalance. For instance, if the rotor **902** still has a slight imbalance, there may be a particular rotational speed where the vibration amplitude spikes (a resonance). The analysis module **912** would detect the frequency/RPM of such a spike and classify it as a critical resonance to address. The rotor **902** to the analysis module **912** as shown in Fig. 9 indicate that the analysis module **912** can also utilize operational data of the rotor to monitor how the rotor is behaving in reality. The analysis module **912** thus acts as a monitoring and diagnostic unit, using both simulated predictions and real feedback to judge if the rotor **902** is within acceptable vibration and balance limits.

[0059] In an exemplary embodiment, the system **900** is designed to iteratively refine the rotor's balance by looping the simulation and analysis results back to the balancing process. As shown in Fig. 9, the simulation module **910** and the analysis module **912** is directed toward the balancing unit **908**. These represent the feedback from the simulation module **910** and the analysis module **912**, based on which the balancing unit **908** adjusts the material removal to ensure the rotor maintains an optimal balance under varying operational conditions. The balancing unit **908** is configured to dynamically adjust the amount of material to be removed in response to feedback from the simulation module **910** regarding rotor balance. The analysis module **912** may also feedback instructions if, for example, a specific mode shape or critical speed issue is detected – ensuring that not only is the rotor balanced in the magnitude sense, but also that its vibrational behavior is optimized. Through this iterative feedback loop between the balancing unit **908**, simulation module **910**, and analysis module **912**, the system **900** converges on an optimal solution where the rotor **902** is balanced within the desired tolerance and all critical resonant conditions are mitigated. By the end of the process, the rotor's imbalance should be reduced to within the permissible residual specific unbalance, and any potential resonances are shifted away from the operational range (for instance, the first critical speed might be pushed above the maximum service speed of the motor This results in significantly improved Noise, Vibration, and Harshness (NVH) characteristics for the motor, as the whirling effect of the rotor is minimized and critical frequencies are all kept above the normal operating region. The outcome is a smoother and more reliable electric motor operation, with reduced vibration-induced wear on components like bearings and housing.

[0060] The interface **906** plays an important role throughout the balancing operation by providing real-time user interaction and monitoring. As noted, the interface initially accepts user inputs for service speed and balance grade and displays the computed permissible imbalance. Beyond this, the interface **906** is configured to support the dynamic aspects of the balancing process. For example, the interface **906** is configured to allow manual adjustment of the service speed **110** and balance quality grade to simulate different rotor balancing scenarios. The interface **906** also provides continuous feedback to the user about the rotor's condition. In particular, the interface provides visual feedback of the rotor's unbalance state before and after material removal based on the simulation results. Additionally, the interface **906** includes controls enabling the user to directly manage the balancing operation. For instance, the interface **906** includes controls for the user to initiate and stop the material removal process based on real-time simulation data. The electric vehicle motor balancing system **900** achieve a balanced rotor according to the desired quality grade. As illustrated in Fig. 9, the system **900** of the present disclosure begins by calculating the allowed imbalance for the rotor **902** at a given service speed **110**, then physically corrects the rotor's balance via controlled material removal, and continuously verifies and refines this balance using advanced simulation and analysis feedback loops.

[0061] **Fig. 10a** illustrates a rotor end plate of the rotor **902** at unbalanced state, in accordance with an embodiment of the present disclosure. In an exemplary embodiment of the present disclosure, the rotor **902** is depicted in its initial, unbalanced state prior to any material removal. The rotor **902** includes end plates at each axial end from which material can be removed to adjust rotor balance. In this pre-balancing illustration as shown in fig. 10a, the end plate is intact and exhibits no material removed areas, indicating that the rotor is in its original unbalanced condition. This unbalanced state corresponds to the rotor's weight distribution before correction – any slight asymmetry in mass around the rotational axis remains unmitigated at this stage. The two-plane balancing technique (i.e., balancing on both end plates) based on ISO 1940 G2.5 standards is planned to be applied, but Fig. 10a shows the starting point where no balancing corrections have yet been executed. The rotor end plate thus serves as one of the two balancing planes (length segments La **104** and Lb **106**) on rotor **902** where corrective material removal will occur. Fig. 10a depicts a baseline for comparison, highlighting the need for balance correction in order to meet the stringent G2.5 grade requirements at the rotor's service speed. **Fig. 10c** illustrates dynamic unbalance, as per ISO 1940 G2.5, where the center of mass of a rotating body doesn't coincide with its axis of rotation, leading to vibrations

and forces. G2.5 is a balance quality grade indicating a vibration velocity of 2.5 mm/s under specified conditions.

[0062] **Fig. 10b** illustrates the rotor end plate after execution of the balancing process, with multiple material removal zones **1002** visible. These discrete removal zones **1002** on the end plate are the precise areas where the balancing unit **908** has removed material to counteract the rotor's initial mass imbalance. Each material removal zone **1002** corresponds to a location and amount of material that was calculated by the system's calculation unit and simulation module (as depicted in Fig. 9) to optimally reduce unbalance. The targeted removal is guided by the permissible residual specific unbalance determined for the rotor's operating speed and the ISO 1940 G2.5 balance quality grade. In effect, the physical modifications shown in Fig. 10b are a direct implementation of the balancing technique in accordance with the present disclosure. The system identified the heavy spots and directed the balancing unit **908** to remove material at those spots on the end plate. The result is a rotor end plate that has been adjusted such that the rotor **902** mass distribution is now substantially even about its axis. Consequently, the rotor **902** achieves a residual imbalance within the tolerance limit specified for the G2.5 grade, validating that the balanced rotor meets the desired quality standard. This embodiment thus demonstrates how removing material at the calculated positions (zones **1002**) on the rotor end plates yields a balanced rotor in practice. The balanced state achieved (as shown by Fig. 10b) corroborates the efficacy of the claimed invention's two-plane balancing system: the rotor **902**, after material removal via balancing unit **908**, operates with significantly reduced vibration and noise, thereby fulfilling the objectives of improved NVH performance and rotor stability.

Technical advantage of the disclosure

[0063] The ISO1940 G2.5 Grade 2-plane balancing approach in the present disclosure hence helps in effectively reducing noises in the motor of electric vehicles by evenly distributing the weight of the rotor by removing the desired weight from the desired location of the rotor. The balancing of the rotor pushes the frequency and modes of operation away from the motor operating speed and reduces the whirling effect for better Noise Vibrations and Harshness (NVH) characteristics. Additionally, vibrational analysis, mode shape analysis, and unbalance response study may be carried out to understand the vibration, modes, critical speed, whirling orbit and made sure critical frequencies are all above operating region of the motor of the electric vehicle.

[0064] It is to be understood that the disclosure is not to be limited to the specific embodiments disclosed, and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation, unless described otherwise.

[0065] Any combination of the above features and functionalities may be used in accordance with one or more embodiments. In the foregoing specification, embodiments have been described with reference to numerous specific details that may vary from implementation to implementation. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense. The sole and exclusive indicator of the scope of the invention, and what is intended by the applicants to be the scope of the invention, is the literal and equivalent scope of the set as claimed in claims that issue from this application, in the specific form in which such claims issue, including any subsequent correction.

We claim:

1. An electric vehicle motor balancing system (900) comprising:

a rotor (102, 202, 302, 902) divided into two parts of length L_a (104) and L_b (106) and at each part of the rotor (102, 202, 302, 902) includes end plates from which material is removable to adjust rotor balance;

a calculation unit (904) configured to determine a permissible residual specific unbalance for the rotor (102, 202, 302, 902) based on a service speed (110) and a balance quality grade according to ISO 1940 G2.5 standards;

an interface (906) configured to display the permissible residual specific unbalance and to receive input parameters including the service speed (110) and the balance quality grade;

a balancing unit (908) configured to remove material from the end plates of the rotor (102, 202, 302, 902) as directed by the calculation unit (904) based on the input parameters;

a simulation module (910) for simulating rotor (102, 202, 302, 902) dynamics to assess changes in rotor balance from material removal, and

an analysis module (912) for determining critical speeds of the rotor (102, 202, 302, 902) and for monitoring unbalance responses based on operational data of the rotor (102, 202, 302, 902).

wherein the balancing unit (908) is configured to adjust the material removal based on feedback from the simulation module (910) and the analysis module (912), to ensure the rotor (102, 202, 302, 902) maintains an optimal balance under varying operational conditions.

2. The system as claimed in claim 1, wherein the rotor (102, 202, 302, 902) is configured to operate the service speed (110); and

wherein the rotor (102, 202, 302, 902) comprises magnetic materials selected from the group consisting of cobalt, nickel, iron, and combinations thereof.

3. The system as claimed in claim 1, wherein the balancing unit (908) includes a precision material removal tool configured to remove material at specified radii on the rotor end plates,

the specified radii being determined based on the calculated permissible residual specific unbalance.

4. The system as claimed in claim 1, wherein the simulation module (910) is configured to model the rotor (102, 202, 302, 902) and motor housing (304) as flexible bodies to accurately capture mass and stiffness characteristics, and to evaluate changes in rotor (102, 202, 302, 902) dynamic behavior due to material removal.

5. The system as claimed in claim 1, wherein the analysis module (912) includes a critical speed analysis function configured to determine the impact of changes in support stiffness versus shaft stiffness on the rotor's (102, 202, 302, 902) critical speeds.

6. The system as claimed in claim 1, wherein the analysis module (912) includes an unbalance response function configured to detect critical resonance frequencies and corresponding RPMs caused by the rotor's (102, 202, 302, 902) unbalanced mass.

7. The system as claimed in claim 1, wherein the interface (906) is configured to allow manual adjustment of the service speed (110) and balance quality grade to simulate different rotor (102, 202, 302, 902) balancing scenarios.

8. The system as claimed in claim 1, wherein the interface (906) provides visual feedback of the rotor's (102, 202, 302, 902) unbalance state before and after material removal based on the simulation results.

9. The system as claimed in claim 1, wherein the balancing unit (908) is configured to dynamically adjust the amount of material to be removed in response to feedback from the simulation module (910) regarding rotor (102, 202, 302, 902) balance.

10. The system as claimed in claim 1, wherein the interface (906) includes controls for the user to initiate and stop the material removal process based on real-time simulation data.