Vibration and Noise Analysis of The Motor for Electric Vehicles

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Abstract :
EVs (Electric Vehicles) are a type of zero emission car. The aim is for them to be accepted favorably across a broad market, and in order to make them into attractive cars we seek superior performance in addition to silence.
Since EVs, unlike conventional internal-combustion engines, are driven by motors, the Vibration and Noise phenomenon resulting from the motor becomes a problem.
A motor's excitation force shifts to the high frequency side compared to an ICE, so it becomes necessary for the motor's vibration and noise analysis to be carried out into higher frequencies.
Today we will introduce the motor's vibration and noise analysis using both magnetic field analysis and vibration and noise analysis.

Vibration and Noise Analysis of the Motor for an Electric Vehicle

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Takayuki Miyakawa, Toshio Enomoto, Hatsuda Tadayuki, and Tsutomu Tanimoto

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1. Self introduction and overview
2. Efforts taken for the environment and the appeal of electric vehicles
3. Vibration and noise phenomena in EV motors
   - 3-1. Motor vibration and noise phenomena challenges
   - 3-2. Motor vibration and noise analysis
   - 3-3. Comparative verification results of experiments and analysis
   - 3-4. The mechanisms behind motor vibration and noise
4. Introducing a case example of motor vibration reduction measures
5. Conclusion

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NISSAN Zero Emission

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1. Self introduction

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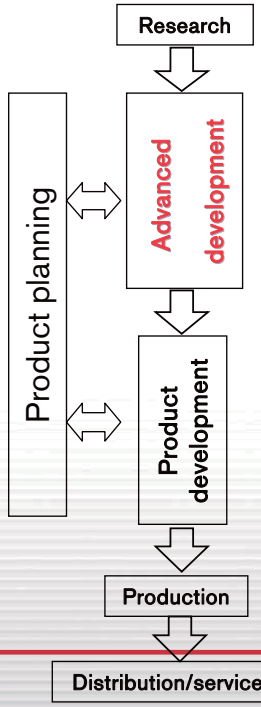
■ The Advanced Vehicle Group's Drive System Development team and the Vehicle Performance Group'sNoise and Vibration Performance Engineering Gr.team are carried out in coordination with each other.



Research Institute

•Advanced Engineering Development
- Advanced Vehicle Engineering Departmen
- Vehicle Performance Engineering Department
- Advanced Drive System Development
- Advanced Noise and Vibration Performance Development

•Product Development Div
- •Body Structure and Body Design Engineering Gr
- •Interior and Exterior Trim Design Engineering Gr
- •Safety Performance Engineering Gr
- •Noise and Vibration Performance Engineering Gr
- • Vehicle Dynamics Engineering Gr
- :
- •Component Engineering Development Div.
- •Electronics Engineering Development Div.

Vehicle production factories
(Japan (Tochigi, Kyushu, Oppama), USA, UK, Russia, China, Thailand, India…)

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1. Overview

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Vehicle performance

- Having all of our customers feel the quality of our vehicles in every scenario
- The market looks for quietness in electrical vehicles

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2. Efforts taken for the environment

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Development history

- Spreading internal combustion engine vehicles that have raised their efficiency to the ultimate level.
- Spreading electric vehicles and accumulating reliable technology for them.

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2. The appeal of electric vehicles

NISSAN Zero Emission

- A sense of driving not

Making the “feeling of excitement and surprise” a reality

- A sense of driving not felt until now

→ Quietness

→ Acceleration

→ Handling

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2. Leaf's appeal

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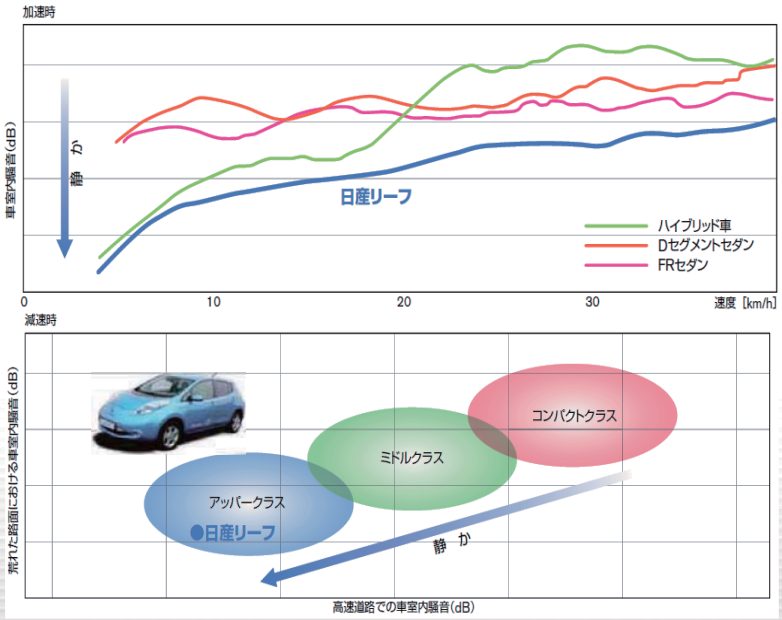
Nissan Leaf (An electric vehicle) has achieved an superior Quietness in all situations, including idling, accelerating, and cruising.



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5. Conclusion

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3. Vibration and noise phenomena challenges

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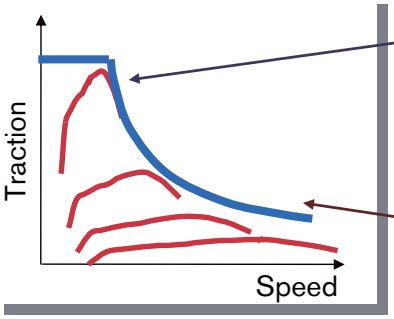
- Motors are generally quieter than internal combustion engines, but motors that have a broad rotation range and high required torque sometimes have vibration and noise issue.
- Because of this, there needs to be technological development for motor Quietness .



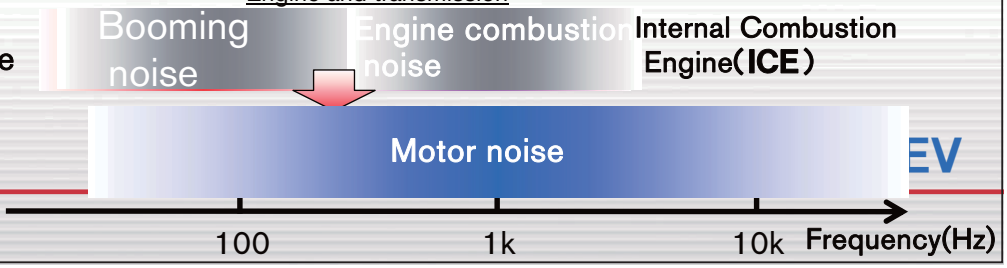
Traction of an engine vehicle and an electric vehicle

Motor

Engine and transmission

EV motors have a broad rotation range and required torque is also high

Vibration and noise generated from a power train



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3. Vibration and noise phenomena challenges

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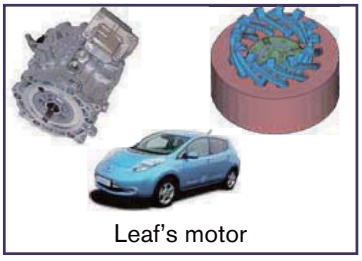
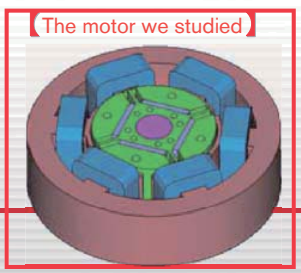
- In order to get high efficiency, high torque, and high output, we performed tests on vehicle drive motors with an emphasis on permanent magnet synchronous motors with interior magnets.
- I would like to introduce a case of a basic study using a concentrated winding motor

- DC Motor
- AC Motor
  - Induction motor (IM)
  - Synchronous motor (SM)
    - Wound field
    - Permanent Magnet Synchronous Motor
      - Surface Permanent Magnet Synchronous Motor
      - Interior Permanent Magnet Synchronous Motor
        - Distributed winding
        - Concentrated winding



Leaf's motor

The motor we studied



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3. Vibration and noise phenomena challenges

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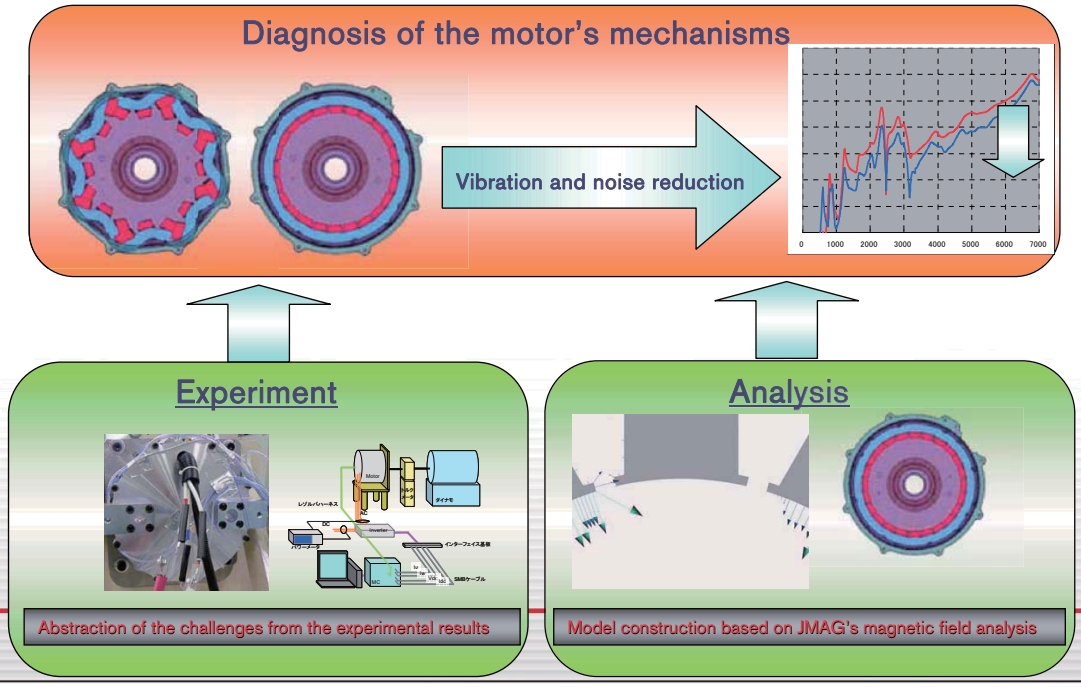
- In order to achieve a reduction in the motor's vibration and noise we approached it from both experimental and analytical standpoints and diagnosed the mechanisms.

The vibration and noise reduction study process



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3. Motor vibration and noise analysis

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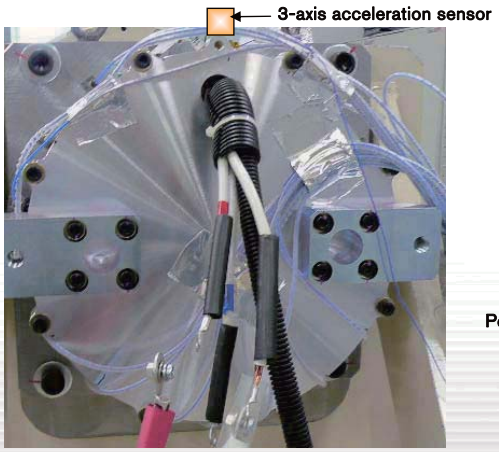
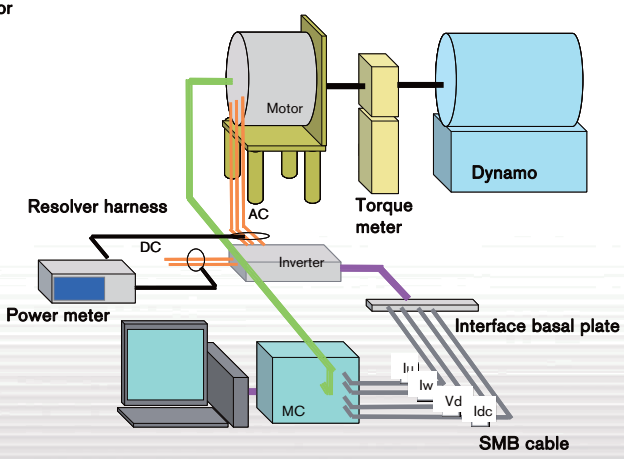
- We created a concentrated winding motor prototype and set it up on a bench.
- We attached several 3-axis acceleration sensors in the motor and performed a vibration experiment.

<Test motor>



<Experimental device configuration>



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3. Motor vibration and noise analysis

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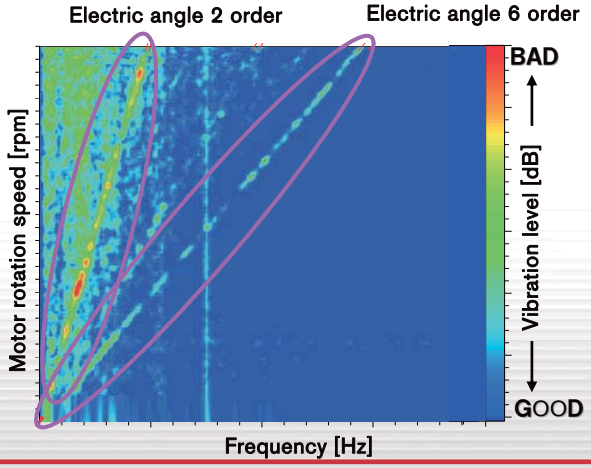
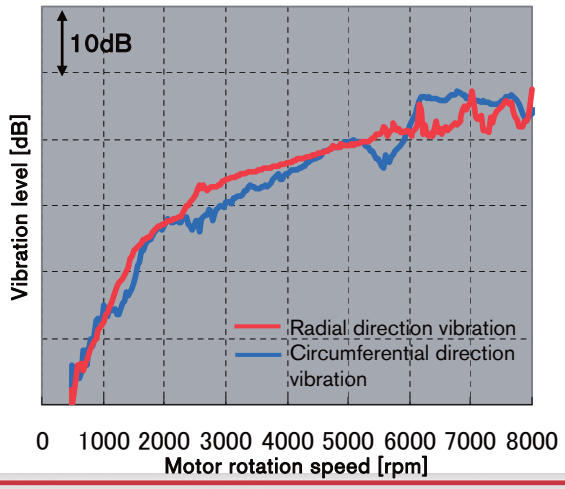
- The experimental had the following two challenges:
  1. In addition to the electric angle 6 component, the 2 component was big as well.
  2. Vibration was large in the radial direction in addition to the circumferential direction.

<A 3D map of the motor's rotation speed, frequency, and vibration level> >



<Vibration levels in the motor's radial and circumferential directions>



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3. Motor vibration and noise analysis

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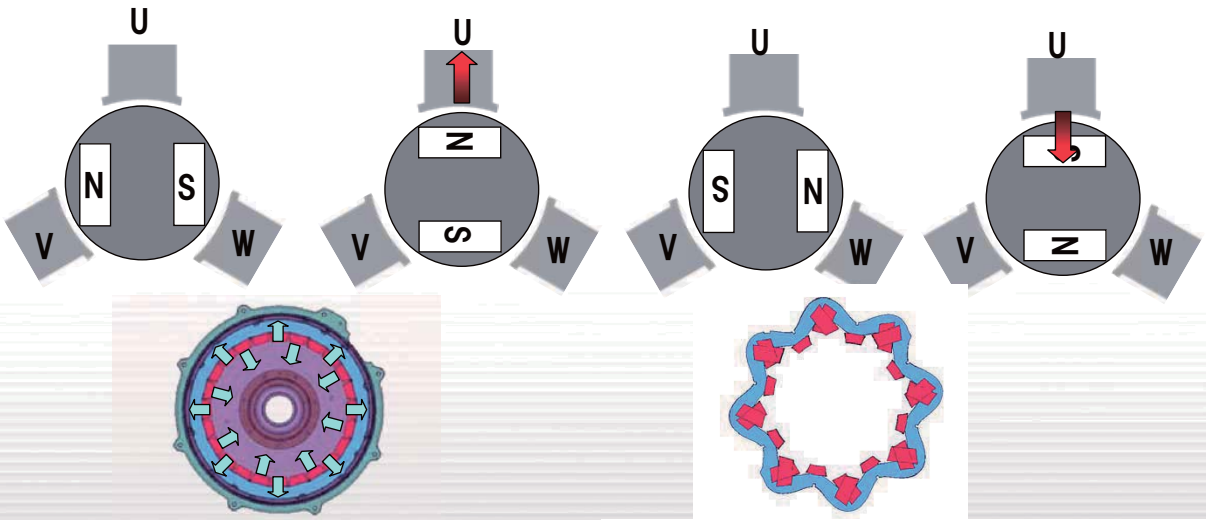
- The excitation force for electric angle 2 is a force that is input to the starter twice for every single electrical rotation of the motor.
- In ideal conditions the net force of electric angle 2's electromagnetic excitation force is zero, but the stiffness of the motor case and stator is low, so there are times when vibration occurs in electric angle 2.



In ideal conditions (Completely rigid body), the net force of the electromagnetic excitation force is zero.

In reality, the motor case and stator are not very rigid, so there are times when vibration occurs in electric angle 2.

3. Motor vibration and noise analysis

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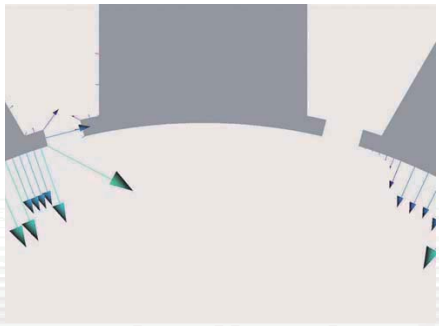
■ We carried out the motor vibration and noise analysis based on the theoretical formula below

$$[F(\omega)] \times [H(\omega)] = [X(\omega)]$$

Excitation Force x Transfer (Resonance) = Response (Noise and Vibration)

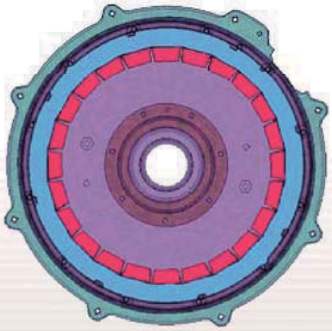
[Magnetic field analysis with JMAG]



Calculating the electromagnetic excitation force input to the stator and rotor

Electromagnetic excitation force

[Vibration analysis with NASTRAN]



Predicting the vibration in the motor's radial and circumferential directions

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3. Motor vibration and noise analysis

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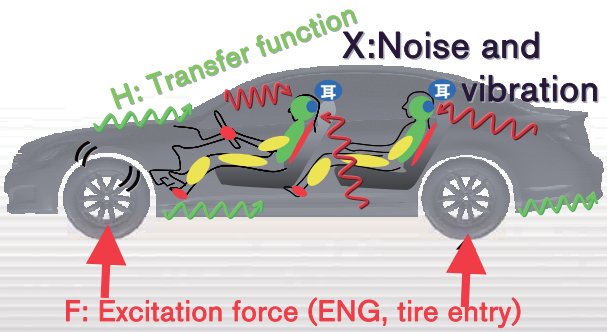
■ The response is a multiplication between the excitation force and the transfer function
■ The transfer function is an overlapping between several eigenmodes

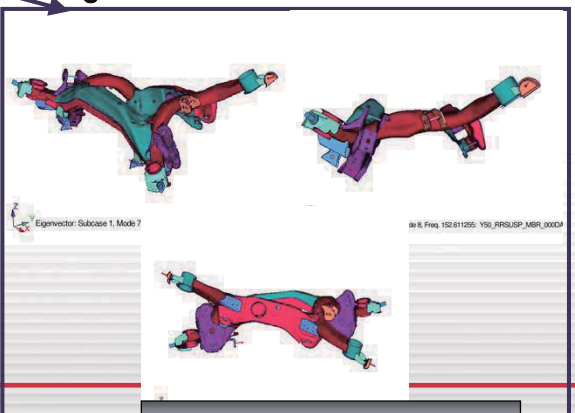
$$[F(\omega)] \times [H(\omega)] = [X(\omega)]$$

Excitation force x Transfer (Resonance) = Response(Noise and vibration)

Conceptual diagram



Eigenmodes



Overlap of several modes

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3. Motor vibration and noise analysis

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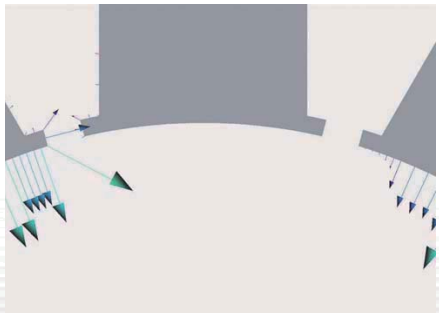
In JMAG, an magnetic field analysis software, we calculated the electromagnetic excitation force (F) entered in the stator and rotor, and used NASTRAN for the structural calculations (H and X)

$$[F(\omega)] \times [H(\omega)] = [X(\omega)]$$

Excitation Force x Transfer (Resonance) = Response (Noise and Vibration)

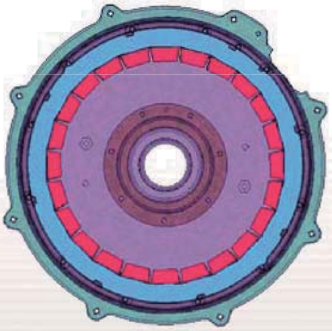
[Magnetic field analysis with JMAG]



Calculating the electromagnetic excitation force input to the stator and rotor

Electromagnetic excitation force

[Vibration analysis with NASTRAN]



Predicting the vibration in the motor's radial and circumferential directions

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3. Motor vibration and noise analysis methods

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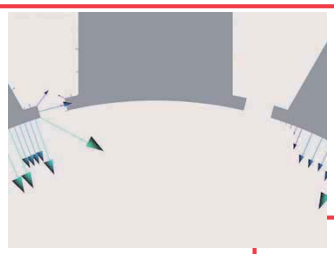
We did order analysis on the time series electromagnetic excitation force that occurs in the surfaces of the stator and rotor calculated in JMAG, defined it as the force of the frequency range in NASTRAN, and calculated the vibration.

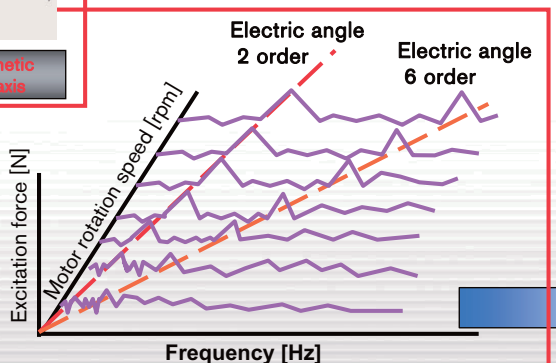
$$[F(\omega)] \times [H(\omega)] = [X(\omega)]$$

Excitation force x Transfer (Resonance) = Response (Noise and vibration)

[Magnetic field analysis with JMAG]

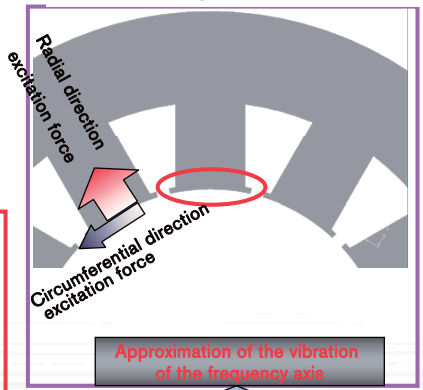


Calculation of the electromagnetic excitation force on the time axis



Calculation of the electromagnetic excitation force of each order component

[Vibration analysis with NASTRAN]



Approximation of the vibration of the frequency axis

We entered the electromagnetic excitation force in the radial, circumferential, and axial directions for each order component for the teeth faces and the rotor face, and then approximated the motor's vibration.

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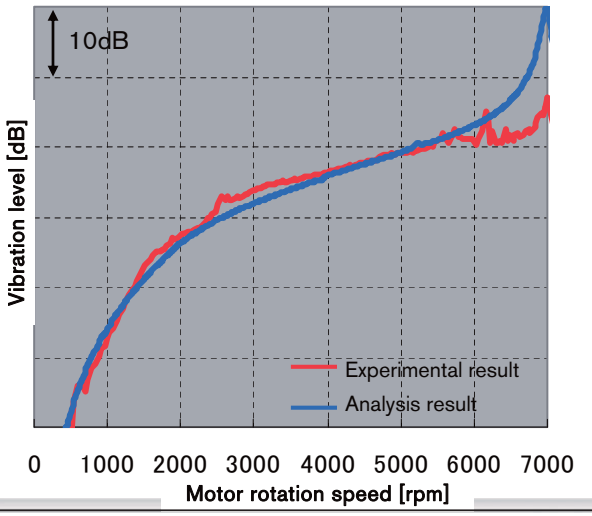
3. Comparative verification results of experiments and analysis

- We were able to recreate the actual vibration of the motor's electric angle 2 and 6 components with good accuracy
  We constructed an analysis model and it became possible to analyze the mechanisms

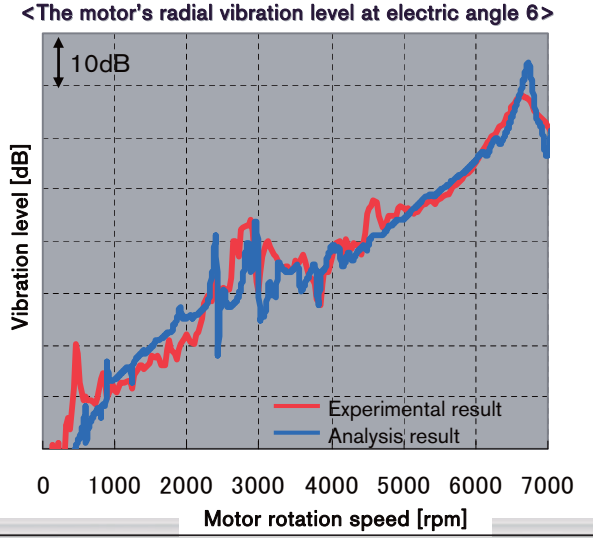
$$[F(\omega)]\times[H(\omega)]=[X(\omega)]$$

Excitation force x Transfer (Resonance) = Response (Noise and vibration)

<The motor's radial vibration level at electric angle 2>



<The motor's radial vibration level at electric angle 6>



3. The mechanisms behind motor vibration and no

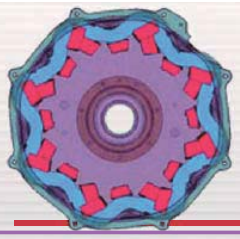
- We found the following generation mechanisms for the motor that we studied this time
  1.The electric angle 2 component is the actual operating mode that switched over as a result of the toroidal 8 mode.
  2.The electric angle 6 component is the actual operating mode that switched over as a result of the toroidal 0 mode.
- We were able to get a handle on the main mode that was becoming a problem and obtain efficient countermeasures that gave insight to its essence

$$[F(\omega)]\times[H(\omega)]=[X(\omega)]$$

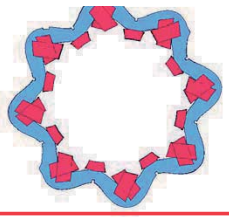
Excitation force x Transfer (Resonance) = Response (Noise and vibration)

<Electric angle 2>

<The motor's actual operating mode>

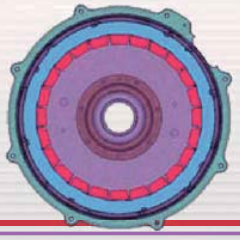


<The eigenmode that excites the actual operating mode>

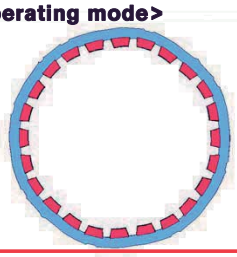


<Electric angle 6>

<The motor's actual operating mode>



<The eigenmode that excites the actual operating mode>



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4. Introducing a case example of motor vibration reduction measures

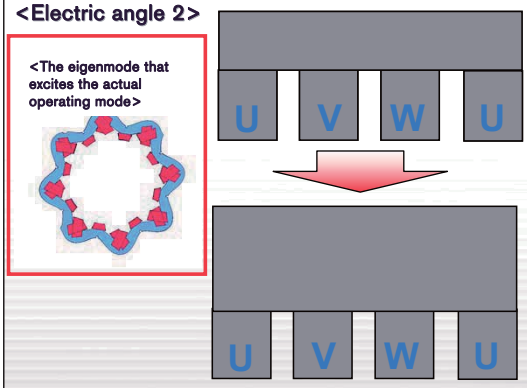
- In order to control the bending moment, we improved the motor's rigidity and transmission system
- We confirmed that the motor's vibration reduces in a high-accuracy model.

$$[F(\omega)] \times [H(\omega)] = [X(\omega)]$$

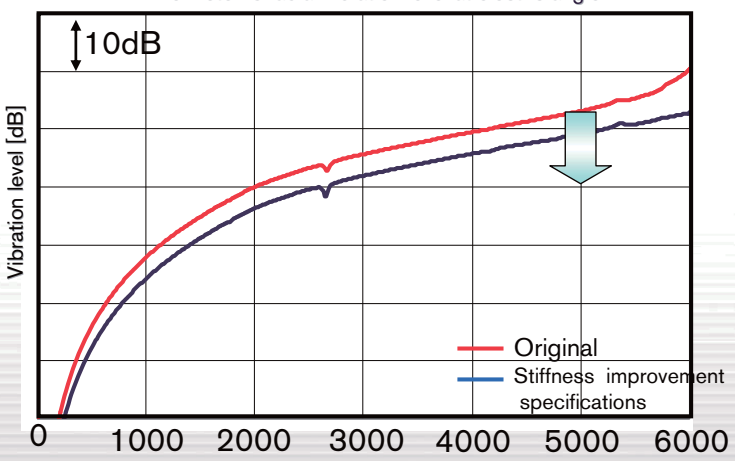
Excitation force x Transfer (Resonance) = Response (Noise and vibration)

In order to control the bending moment we made the case and back yoke thicker and improved the stiffness

<Electric angle 2>



<The motor's radial vibration level at electric angle 2>



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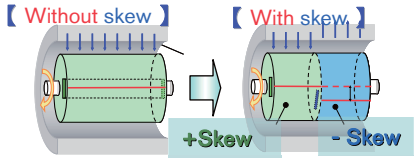
4. Introducing a case example of motor vibration reduction measures

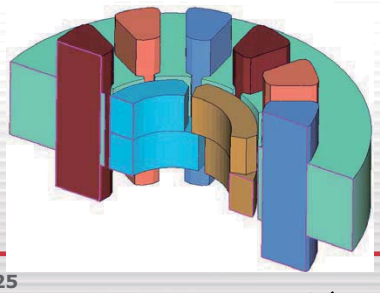
- We calculated the electromagnetic excitation force from the rotor skew with JMAG's3D analysis.
- We confirmed that the motor's vibration decreased in a high accuracy model.

$$[F(\omega)] \times [H(\omega)] = [X(\omega)]$$

Excitation force x Transfer (Resonance) = Response (Noise and vibration)

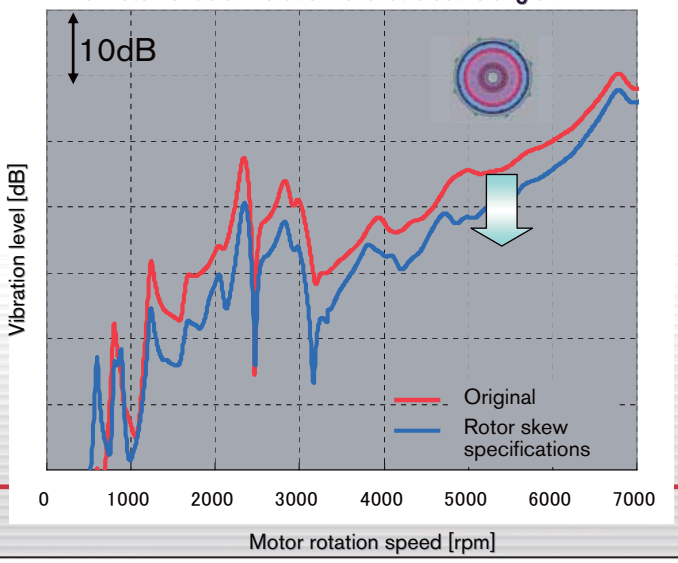


It mechanically displaces the magnet in the rotor and negates the excitation force from electric angle 6.



A 3D model of the skew with JMAG (An image)

<The motor's radial vibration level at electric angle 6>



5. Conclusion

- In addition to the electric angle 6 component, there are cases when other orders (Electric angle 2) become issue as well.
- There are cases when vibration in the radial direction, not just the circumferential direction, becomes a problem.
- We were able to construct high accuracy models with JMAG and NASTRAN.
- I introduced a study case for motor vibration reduction countermeasures (Stiffness improvement and rotor skew).

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