Sound and Vibration in Rolling Bearings

Tatsunobu Momono and Banda Noda
Basic Technology Research and Development Center

ABSTRACT

Progress in information technology devices and the proliferation of these devices throughout the world have occurred at an astonishingly rapid pace. Not only have there been remarkable improvements in computers, automobiles and electric home appliances, but the total number of such products owned and used by people has increased dramatically.

In the midst of such advancement, demand has grown for rolling bearings with lower vibration and noise. In response, extensive research and development has been undertaken at NSK.

This report summarizes some of the key findings accumulated from research on sound and vibration in bearings, and discusses vibration modes of bearing rings. In addition, a useful table summarizing sound and vibration in bearings is included as a convenient reference tool for the reader.

1. Introduction

Progress in information technology devices has occurred at a dizzying pace and the widespread use of these devices has been truly remarkable. Personal computers are found in businesses and homes throughout the world and it appears that improvements in their performance have no end in sight. At the same time, new software and peripheral devices are appearing on an almost daily basis. As for performance improvement of office automation

Table 1 Classification of sound and vibration in rolling bearings

	Sound		Vibration		Features
Structural	Race noise		Free vibration of raceway ring		Continuous noise, basic unavoidable noise which all bearings generate
	Click noise		Free vibration of raceway ring, free vibration of cage		Regular noise at a certain interval, large bearings and horizontal shaft, radial load and low rpm
	Squeal noise		Free vibration of raceway ring		Intermittent or continuous, mostly large cylindrical roller bearings, radial load, grease lubrication, at particular speed
	Cage noise	"CK" noise	Free vibration of cage		Regular noise at a certain interval, all bearing types generate it
		"CG" noise	Vibration of cage		Intermittent or continuous, lubrication with particular grease
		Tapping noise	Free vibration of cage		Certain interval, but a little irregular under radial load and during initial stage
	—		Rolling element passage vibration		Continuous, all bearing types under radial load
Manufacturing	Waviness noise		Vibration due to waviness	Inner ring	Continuous noise
				Outer ring	Continuous noise
				Rolling element	Continuous with rollers, occasional with balls
Handling	Flaw noise		Vibration due to flaw	Inner ring	Regular noise at a certain interval
				Outer ring	
				Rolling element	
	Contamination noise		Vibration due to contamination		Irregular
Others	Seal noise		Free vibration of seal		Contact seal
	Lubricant noise		—		Irregular
	—		Runout	f_r	Continuous
				f_c	Continuous
				$f_r - 2f_c$	Continuous

equipment, particularly personal computers and related products, demand is high for ever-lower vibration and sound levels of moving components. In the automotive and home appliance industries, performance improvement continues unabated and the average number of such products owned by households increases steadily. For consumer goods such as air conditioners, washing machines, refrigerators, vacuum cleaners and automobiles, quietness is a key selling point that often helps clinch sales.

Amid these market conditions, requirements for low vibration and sound in rolling bearings become more severe every year. At NSK, intensive R&D is being undertaken to meet such requirements, particularly for small and ultra-small ball bearings. For example, results of research on low vibration and low noise in VCR bearings served as the foundation for NSK's recently developed HDD bearings, which are acclaimed for their world-class quality. In this report, we discuss vibration and sound in rolling bearings based on key findings from past research.

2. Classification of Vibration and Sound in Bearings

The various types of vibration and sound in rolling bearings are grouped into the four categories listed in Table 1.[1] While other ways of classifying vibration and sound exist, the discussion in this report is based on the classification system in this table. In this classification system, the distinctions between the categories are not absolute. For example, the magnitude of structural sound or vibration is partially related to the manufacturing process. When sound is generated, in most cases vibration occurs, and when vibration occurs, usually sound is generated. For example, when vibration is caused by waviness, it is assumed that at the same time a "waviness sound" is generated. While vibration and sound almost always accompany each other, problems of vibration and sound are usually characterized in terms of one or the other. This is because the ability or inability of humans to hear sound or sense vibration depends on frequency. Low-frequency sound is barely audible while high-frequency vibration cannot be perceived by humans. For this reason, problems at low frequency are "vibration problems," and

Table 1 (continued)

Generated frequency (frequency analysis)			Source	Countermeasures
FFT of original wave		FFT after envelope (basic No.)		
Radial (angular) direction	Axial direction			
f_{RiN}, f_{M1}	f_{AiN}, f_{AM}	—	Selective resonance of waviness (rolling friction)	Improve rigidity around the bearings, appropriate radial clearance, high-viscosity lubricant, high-quality bearings
f_{RiN}, f_{M1} Natural frequency of cage	f_{AiN}, f_{AM}	Zf_c	Collision of rolling elements with inner ring or cage	Reduce radial clearance, apply preload, high-viscosity oil
(≈ f_{R2N}, f_{R3N})	—	?	Self-induced vibration caused by sliding friction at rolling surface	Reduce radial clearance, apply preload, change the grease, replace with countermeasured bearings
Natural frequency of cage		f_c	Collision of cage with rolling elements or rings	Apply preload, high-viscosity lubricant, reduce mounting error
Natural frequency of cage		?	Self-induced vibration caused by friction at cage guide surface	Change the grease brand, replace with countermeasured cage
Natural frequency of cage		Zf_c	Collision of cage and rolling element caused by grease resistance	Reduce radial clearance, apply preload, low-viscosity lubricant
Zf_c	—	—	Displacement of inner ring due to rolling element passage	Reduce radial clearance, apply preload
$nZf_i \pm f_r$ ($nZ \pm$ 1 peaks)	nZf_i (nZ peaks)	—	Inner ring raceway waviness, irregularity of shaft exterior	High-quality bearings, improve shaft accuracy
nZf_c ($nZ \pm$ 1 peaks)	nZ_{fc} (nZ peaks)	—	Outer ring raceway waviness, irregular bore of housing	High-quality bearings, improve housing bore accuracy
$2nf_b \pm f_c$ ($2n$ peaks)	$2nf_b$ ($2n$ peaks)	—	Rolling element waviness	High-quality bearings
f_{RiN}, f_{M1}	f_{AiN}, f_{AM}	Zf_i	Nicks, dents, rust, flaking on inner ring raceway	Replacement and careful bearing handling
		Zf_c	Nicks, dents, rust, flaking on outer ring raceway	Replacement and careful bearing handling
		$2f_b$	Nicks, dents, rust, flaking on rolling elements	Replacement and careful bearing handling
f_{RiN}, f_{M1}	f_{AiN}, f_{AM}	Irregular	Entry of dirt and debris	Washing, improve sealing
Natural frequency of seal		(f_r)	Self-induced vibration due to friction at seal contact area	Change the seal, change the grease
?	?	Irregular	Lubricant or lubricant bubbles crushed between rolling elements and raceways	Change the grease
f_r	—	—	Irregular inner ring cross-section	High-quality bearings
f_c	—	—	Ball variation in bearing, rolling elements non-equidistant	High-quality bearings
$f_r - 2f_c$	—	—	Non-linear vibration due to rigid variation by ball variation	High-quality bearings

n: Positive integer (1, 2, 3...)
Z: Number of rolling elements
f_{RiN}: Ring natural frequency in radial bending mode, Hz
f_{M1}: Natural frequency in the mode of angular vibration in inertia of outer ring-spring system, Hz
f_r: Rotation frequency of inner ring, Hz
f_c: Orbital revolution frequency of rolling elements, Hz
f_{AiN}: Ring natural frequency in axial bending mode, Hz
f_{AM}: Natural frequency in the mode of axial vibration in mass of outer ring-spring system, Hz
f_i: $f_i = f_r - f_c$, Hz
f_b: Rotation frequency of rolling element around its center, Hz

those at high frequency are “noise problems.” As a rule of thumb, the arbitrary border separating vibration problems from noise problems is 1 000 Hz. In other words, below 1 000 Hz is considered to be vibration and above 1 000 Hz is sound or noise.

3. Types of Vibration and Sound in Bearings

3.1 Structural vibration and sound

Even when the most advanced manufacturing technology is used, vibration and sound still occur naturally in rolling bearings. As such vibration and sound do not degrade bearing performance, they are accepted as normal bearing characteristics.

3.1.1 Race noise

Race noise is the most basic sound in rolling bearings. It is generated in all bearings and is a smooth and continuous sound. At NSK we say it sounds like “sha-ahh.” The magnitude of this sound is used to assess bearing quality. Fig. 1 shows how the magnitude of race noise compares to familiar sounds.[2] In this figure, even the sound generated by the loudest of the bearings, bearing #6410, is only about 1/100 of the magnitude of normal conversation. It is clear that the energy associated with race noise is very limited. The characteristics of race noise are as follows:[3]

(1) The frequency of the sound does not change even when rotational speed changes. Its frequency is the natural frequency of the raceway rings, as illustrated in Fig. 2.
(2) The faster the running speed, the louder the sound.
(3) If radial clearance is reduced, the sound becomes louder.
(4) As for the lubricant, when its viscosity is higher the sound is reduced. Besides the viscosity of the grease, the consistency, form and size of the soap fiber in it also affect noise performance.
(5) The higher the rigidity of the housing, the lower the magnitude of the sound.

Race noise is considered to be caused by configuration error (called microundulation or waviness), which occurs even when the most advanced machining technology is used to process the surfaces of the raceways and rolling elements of a bearing. Due to this waviness, the contact between the raceway rings and rolling elements behaves like a spring that fluctuates minutely during bearing operation. The variation of this so-called spring acts as an excitation force on the raceway rings of the bearing. Consequently, vibration and race noise are generated.

The generation of race noise is inevitable and there are no special countermeasures to eliminate it completely. However, it can be minimized by improving the overall quality and precision of bearings.

3.1.2 Click noise

Click noise tends to occur more often in relatively large bearings under radial loads. It is generated only at low speeds, disappearing when speed exceeds a certain level. A rough approximation of this noise used at NSK is “kata kata.” It is somewhat similar to flaw noise, which is described in a following section. The generation of click noise is believed to proceed as follows (Fig. 3). When a bearing is operated under a radial load, then a load zone and no-load zone exist inside the bearing. The bearing has some clearance in the no-load zone—rolling elements do not touch the inner ring, but do touch the outer ring due to centrifugal force (F_{c2}). However, at low speeds, when centrifugal force becomes less than the force of gravity (W_1), the rolling elements fall and collide with the cage and/or inner ring. It is the collisions between the rolling

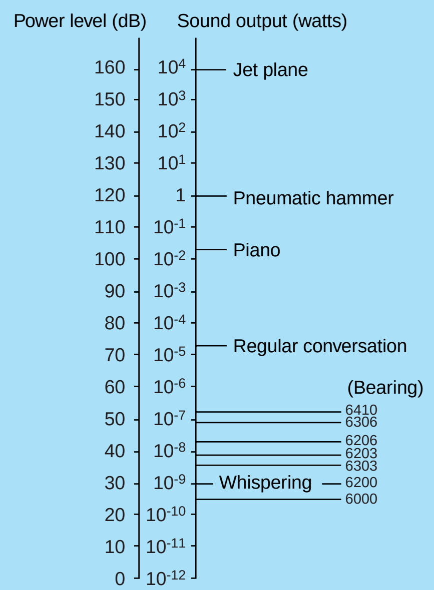


Fig. 1 Loudness range of race noise

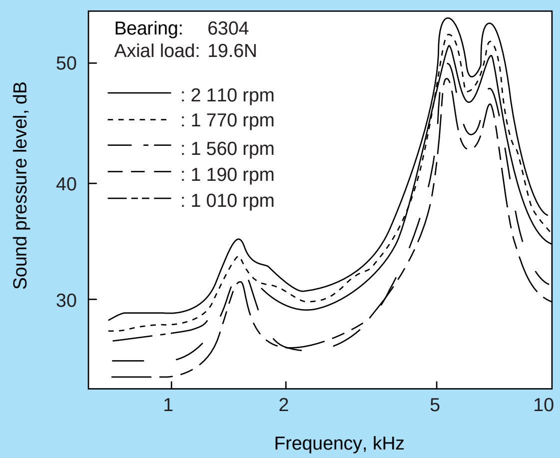


Fig. 2 Influence of rotation speed on race noise

elements and the cage and/or inner ring that generate click noise.

Applying a preload is an effective countermeasure to click noise. Reducing radial clearance results in only a small improvement. Another remedy is using light rolling elements like those made of ceramic.

3.1.3 Squeal noise

Squeal noise is a metallic noise that can be rather loud in some cases. It sounds like metal sliding on metal and we express it in Japanese as “kyuru kyuru.” With squeal noise, bearing temperature does not generally rise and bearing and grease life are not adversely affected. In fact, beyond the noise problem (if indeed it is actually a problem), there is no other hindrance to bearing operation. Squeal noise tends to occur with relatively large bearings used under a radial load. It occurs frequently in cylindrical roller bearings, but may also occur in ball bearings. The characteristics of squeal noise are:

(1) It tends to occur when radial clearance is large.
(2) It occurs mostly with grease lubrication and only rarely with oil lubrication.
(3) It occurs more often in winter.
(4) It occurs within a certain speed range that tends to become lower as bearing size increases.
(5) Its generation is inconsistent and unpredictable, and depends on the kind and amount of grease, as well as bearing operating conditions.

Influenced by the lubrication used and increasing vibration of the outer ring, the friction between the outer ring and rolling elements is considered to be the cause of squeal noise. Squeal noise is attributed to self-induced vibration related to lubrication. However, there is an important question: From what part of the circumference of the outer ring is squeal noise emitted? The jury is still out on this question as some experts believe the noise is generated in the load zone while others argue that it is generated in the no-load zone.[4),5)] Effective countermeasures to squeal noise include reducing the radial clearance and employing a very shallow groove in the outer ring raceway of the bearing.[6)]

3.1.4 Cage noise

There are two kinds of cage noise: a noise suggestive of the cage colliding with rolling elements or bearing rings (“kacha-kacha” at NSK) and a low-frequency noise (“gaga gaga”). NSK differentiates them by calling them “CK noise” and “CG noise,” respectively. CK noise can be generated in any type of bearing and the magnitude of it is usually not very high. Characteristics of this noise include:

(1) It occurs with pressed steel cages, machined cages and plastic cages.
(2) It occurs with grease and oil lubrication.
(3) It tends to occur if a moment load is applied to the outer ring of a bearing.
(4) It tends to occur more often with greater radial clearance.

CK noise is attributed to the rotating cage colliding with rolling elements or raceway rings. As there is clearance between the cage and both the rolling elements and raceway rings, it is difficult to completely eliminate CK noise. However, it can be reduced to some extent by reducing the mounting error.

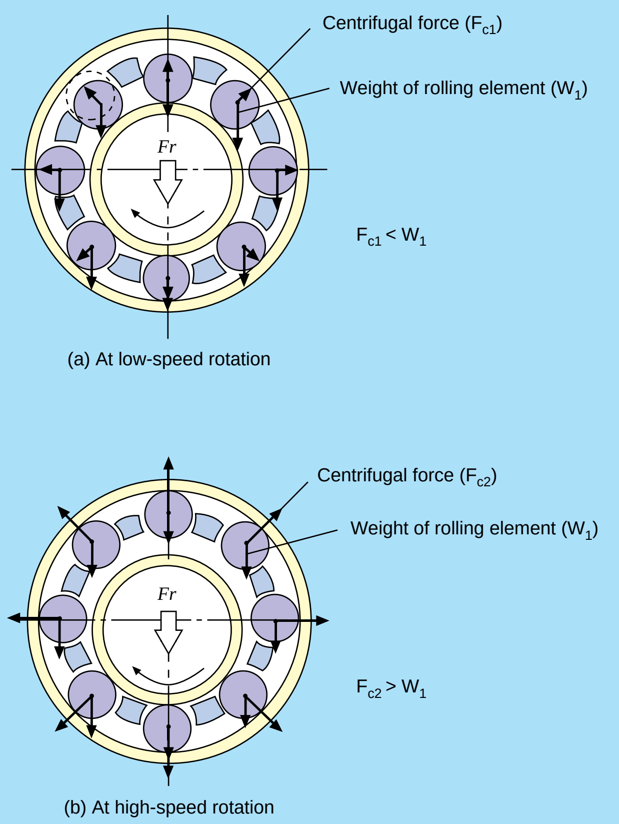


Fig. 3 Mechanism of rolling element falling noise

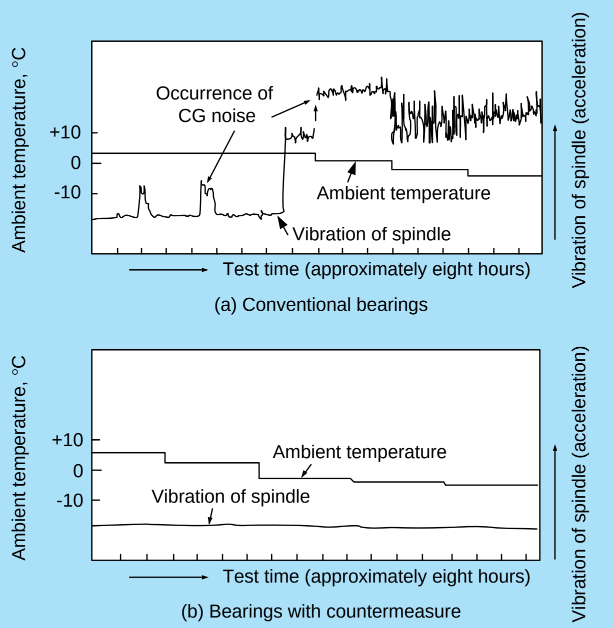


Fig. 4 Performance evaluation test of cage noise (CG noise)

CG noise is a special noise which, in Japan, is perceived as being similar to a croaking frog. It is attributed to self-induced vibration of the cage caused by sliding friction between the cage guide face and the bearing component that guides the cage. It frequently becomes loud and therefore problematic. For this reason, a bearing was specially designed with the expressed purpose of suppressing cage noise of this type.[7] Fig. 4 compares the performance of a conventional bearing, to which no countermeasure was applied, to a bearing with a specially designed cage. The bearings were mounted on a spindle, and because CG noise tends to occur at lower temperatures, ambient temperature was gradually lowered during the test. In the bearing with the specially designed cage, cage noise did not occur even after the ambient temperature went below 0°C. CG noise is generated with grease lubrication and tends to occur with relatively hard grease. The use of the specially designed cage is effective in reducing CG noise, as is the careful selection of lubricant.

When a bearing is used under a radial load with hard grease, a loud cage noise (sounding roughly like "gacha gacha") may occur at the initial stage of rotation. This noise is caused by the rolling elements colliding with the cage as they suddenly decelerate due to grease resistance after departing the load zone. However, this noise becomes negligible and eventually disappears with time.

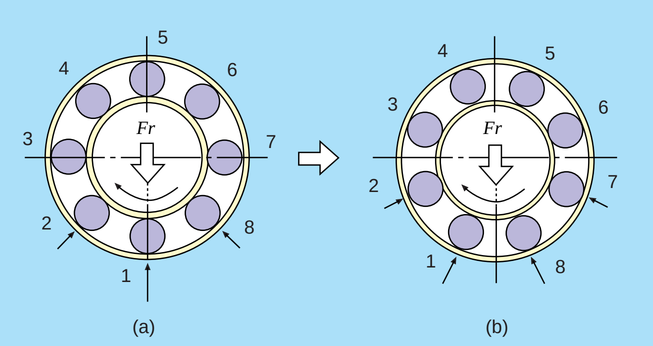


Fig. 5 Mechanism of vibration due to rolling elements passing

3.1.5 Rolling element passage vibration

Rolling element passage vibration becomes a problem mostly in rolling bearings operating under a radial load. When this kind of vibration occurs, the shaft's center of rotation runs out both vertically and horizontally and a noise, which at NSK is expressed as "goro goro," may occur. The amplitude of this vibration is influenced by radial clearance, radial load and the number of rolling elements. This type of vibration occurs due to variation in load sharing that depends both on the position of each rolling element in the load zone and on the minute variation in the amount and direction to which the shaft is displaced. Comparing conditions (a) and (b) in Fig. 5, the displacement of the rotating shaft in the vertical direction is slightly different. The shaft also moves transversely between the conditions shown in the figure. Theoretical and experimental studies indicate that the frequency of this vibration can be expressed as:[8]

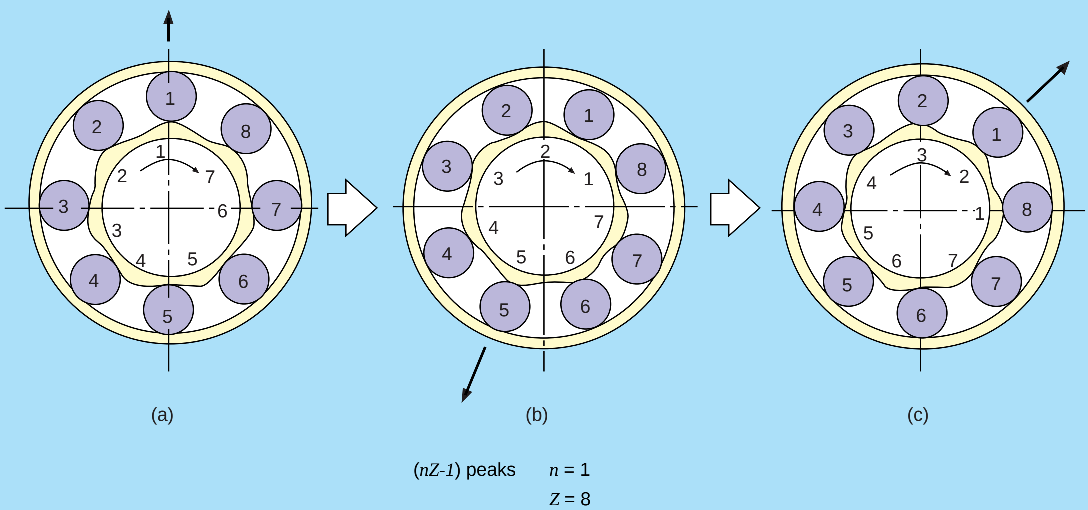
$$f = Z \cdot f_c \ (Hz)$$

Z: Number of rolling elements
f_c: Orbital revolution frequency of rolling elements (Hz)

As rolling element passage vibration is usually of small amplitude, it rarely becomes a problem. When it does become a problem, reduction of radial clearance or application of a preload can be effective countermeasures.

3.2 Vibration and sound related to bearing manufacturing

Vibration and sound related to bearing manufacturing, the most significant type of which is caused by waviness, cannot be eliminated completely. Even with modern



(nZ-1) peaks n = 1
Z = 8

Fig. 6 Mechanism of vibration due to waviness of raceway or rolling element surface precision machining technology, an element of waviness exists that will generate sound and vibration albeit, however, at negligible levels. It is only when waviness is abnormal (due either to factors relating to manufacturing or a particular bearing's application) that waviness noise becomes a problem. Unlike most other sounds generated by rolling bearings, the frequency of waviness noise depends on the speed. This is an important characteristic by which waviness noise can be distinguished from other types of noise. At a constant rotational speed, waviness noise is harsh and has a constant frequency. At NSK we say it sounds like "ooh ooh" or "whan whan." When a bearing is accelerating or decelerating, waviness noise is even more harsh and its frequency increases or decreases with speed. NSK's approximation of this noise is "hee-yun." Waviness noise becomes a problem when the vibration caused by the waviness of the raceways and/or rolling elements is excessive.

Gustafsson conducted a basic study on vibration caused by waviness.[9] He considered waviness in the circumferential direction on the surface of the inner and outer ring raceways and rolling elements as a group of sinusoidal waves. He examined the force balance inside the bearing when such waviness exists and calculated the bearing vibration caused by it. As a result, he determined the number of waviness peaks that cause vibration and the frequency of this vibration. The section of Table 1 regarding the frequency of waviness noise reflects these findings. As it is clear from Table 1, waviness with a specific number of peaks is the cause of this vibration. As is shown in Fig. 6, vibration in the radial direction occurs when waviness with (nZ-1) peaks exists on the inner ring.

Gustafsson's analysis of vibration was based on a constant axial load being applied and only one component having waviness. Since his research, others have analyzed

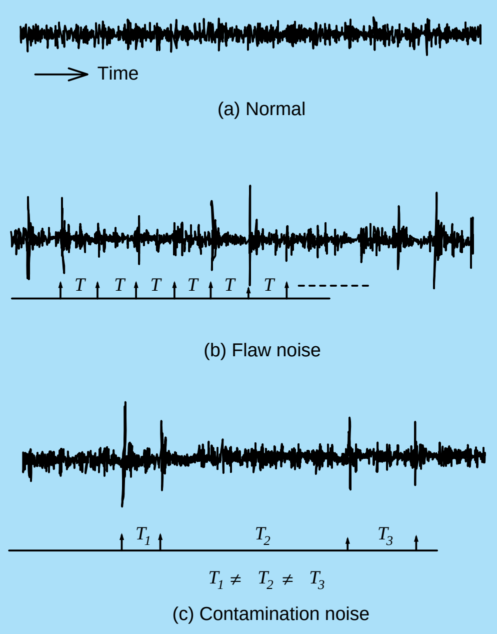


Fig. 7 Waveform of noise due to flaw and contamination

cases where waviness existed on two components and radial load was applied.[10, 11] According to these studies, vibration occurs with additional numbers of waviness peaks. While the generation of vibration and noise with the number of peaks deduced by Gustafsson and shown in Table 1 has been confirmed in numerous cases, not enough experimental data have been gathered to confirm the additional numbers of peaks in the more recent research.

To avoid problems, this vibration (waviness noise) can be reduced by decreasing the waviness in the circumferential direction on the finished surfaces of the bearing components. Additionally, it should be noted that if waviness exists on the fitting face of the shaft or housing to which the bearing is mounted, then this waviness reflects onto the raceway surface of the bearing and generates vibration. If a spline is cut on the shaft, a similar effect may result. Therefore, careful attention is required.

3.3 Vibration and sound due to improper handling

Major components of a bearing have a harder surface than HRC60, so they are usually tough. But if a bearing is dropped or otherwise sustains a shock, dents can result on the finished surfaces of the bearing components. Even a slight defect in shape may cause vibration or sound. In addition to dents and flaws, minute contamination may cause problems. Vibration and sound in this group are mainly caused by improper handling of the bearing.

3.3.1 Flaw noise

When a flaw such as a dent or rust exists on a finished raceway surface of a rolling bearing, then a pulsating, machine-gun-like noise is generated when the bearing rotates. At NSK this noise is expressed as "beee." It is caused by the rolling elements hitting the flaw on the raceway surface and is called flaw noise. As Table 1 shows, its frequency is the same as that of race noise. When flaw noise is generated, the level of the entire frequency spectrum rises. As a result, analyzing the frequency simply by FFT is not sufficient to distinguish it from some other noises. Flaw noise has unique generation cycles or intervals when compared to other types of noise (Fig. 7). At a constant speed, the noise generation cycle is constant, but as the speed decreases, the noise generation cycle becomes longer. This cycle is determined by speed and the internal specifications of the bearing. As Table 1 shows, it also changes with the position of the flaw on the bearing.[12] Due to this characteristic, it is possible to determine whether flaws exist and if so, where they are located. To determine the generation cycle of such a noise, a method called envelope analysis is used.

In the case of a ball bearing with a flaw on a ball, but not necessarily on the rolling surface of the ball, noise due to the flaw sometimes occurs and sometimes does not. When such noise is generated, it will always have a cyclic characteristic.

When grease of high viscosity is used, the noise is masked and the level of the noise tends to be reduced.

However, when noise due to a flaw on a rolling element occurs, usually the bearing should be replaced.

3.3.2 Contamination noise

The ingress of foreign particles into a bearing, either from improper handling or severe operating conditions, results in contamination noise, which at NSK is approximated by “chi chi chi.” It results from foreign particles being caught between the rolling elements and raceway surfaces. The magnitude of contamination noise is not constant and its generation is irregular (Fig. 7). Generally, the smaller the bearing, the larger the influence of foreign particles. Contamination noise frequently is a problem with small-size or extra-small-size bearings. The entry of foreign particles not only causes noise but can also cause dents on the rolling surfaces of the bearing and thereby shorten bearing life. For this reason, preventive measures must be taken.

3.4 Other vibration and sound

The various types of sound and vibration in Table 1 that have been described to this point are fairly well understood. However, the types of sound and vibration in the category titled “Others” are not as well understood. The first of these is seal noise. In a grease-lubricated bearing with contact seals, a “peee” noise may occur. This noise is attributed to self-induced vibration caused by friction between the seals and seal contact points. As a countermeasure, a different kind of seal or grease can be adopted.

During the initial rotation of a bearing with grease lubrication, noises that are roughly equivalent to “pee-shee” or “jyuu” may be heard. These noises are believed to be generated when lubricant or lubricant bubbles are crushed between the rolling elements and raceways. Their generation is irregular and ceases as running time elapses. This type of noise is not considered to be a significant problem as its magnitude is low.

Next we discuss three types of vibration in rolling bearings: the f_r, f_c and f_r-$2f_c$ vibration components. The f_r component is runout that is caused by an unbalanced shaft or uneven thickness of the inner ring. The frequency of this vibration is the same as the rotation frequency. The f_c component occurs if there is a difference in the diameters of the rolling elements or if the arrangement of the rolling elements is not equidistant. The frequency of this component is the same as the orbital revolution frequency of the rolling elements.[13] The f_r-$2f_c$ component occurs when a difference in the diameters of the rolling elements affects the spring characteristics of the shaft and bearing. It has been pointed out that this directional characteristic rotates at f_c, and the frequency of this vibration is the f_r-$2f_c$ frequency.[13] For all of these vibration components, similar to vibration caused by waviness, the frequency varies as rotational speed changes. Waviness, f_c and f_r-$2f_c$ vibration all are components of non-repetitive runout (NRRO) and as such are important topics in HDD research and development.

4. Frequency of Vibration and Sound in Bearings

4.1 Natural frequency of raceway rings

As can be understood from Table 1, many frequencies of vibration and sound generated in bearings are related to the natural frequency of the raceway rings. Of the two raceway rings, the natural frequency of the outer ring becomes a problem more often than the inner ring due to a loose fit between it and the housing. The modes of vibration of the outer ring are roughly divided into two categories: those that consider the outer ring as a rigid body and those that consider it as an elastic body.[3] Besides these, there are modes of vibration associated with each bearing component such as the cage. However, these vibrations have not been systematically studied yet due to the complexity of the modes of vibration and the number of factors involved including shape, material and other variables.

4.1.1 Rigid body modes

For a rigid body, there are two modes of vibration which, for the sake of clarity, we will call mode A and mode B. Mode A is angular vibration in the inertia outer ring-spring system, and mode B is vibration in the mass outer

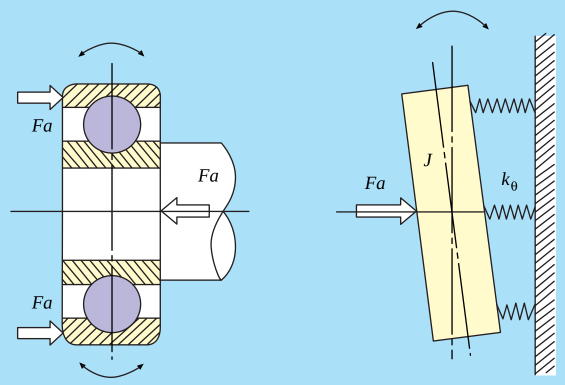


Fig. 8 Mode of angular vibration in inertia of outer ring-spring system

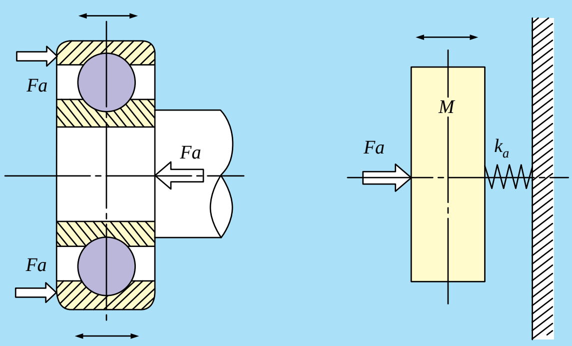


Fig. 9 Mode of axial vibration in mass of outer ring-spring system

ring-spring system. Mode A is illustrated in Fig. 8. Mode B can be divided further into radial and axial vibration, but because radial vibration rarely becomes a problem, only the mode of axial vibration is analyzed. So, mode B is the vibration in the system of the mass of the outer ring and spring in the axial direction of the bearing. It is illustrated in Fig. 9. To find the natural frequency, one needs to determine the spring coefficient of a bearing, which takes a long time. Fortunately, for ball bearings to which a pure axial load is applied, there is a formula which allows natural frequency to be calculated easily.[14)]

4.1.2 Elastic body modes

An example of a vibration mode in which the outer raceway ring is considered as an elastic body is the bending mode. This vibration mode is divided into radial and axial modes, as shown in Fig. 10. In these vibration modes, the outer ring becomes a problem more frequently. There are several formulas for calculating the natural frequency of the bending mode in the outer ring of a ball bearing.[15), 16), 17)] These formulas give the value of the natural frequency when a bearing is free, which for most applications is sufficiently accurate. When higher degrees of accuracy are required, a more complicated method of calculation that takes into account mounting conditions must be used.

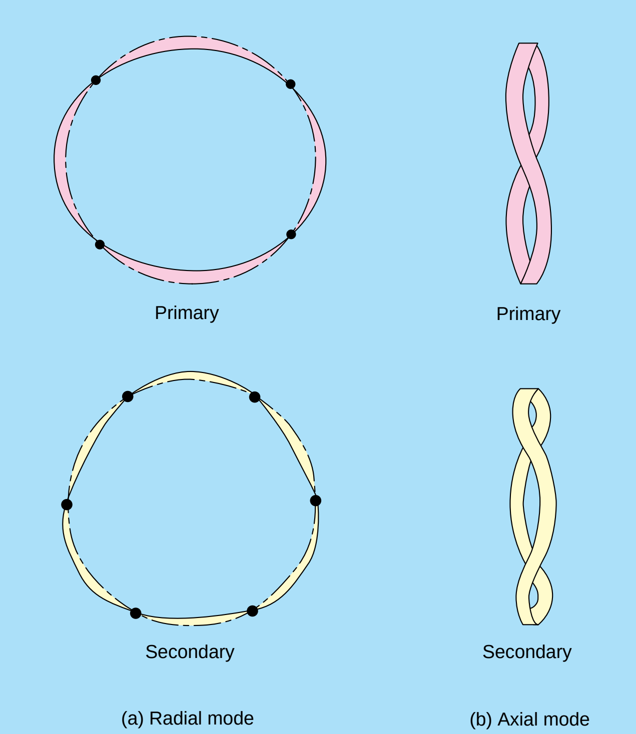


Fig. 10 Mode shapes for bearing rings (bending mode)

4.2 Rotation frequency of rolling elements

As is apparent from Table 1, in order to calculate either the frequency of vibration caused by waviness or the envelope frequency of flaw noise, the orbital revolution frequency of the rolling elements (f_c) and the rolling element frequency (f_b) are required. These values are determined by the internal specifications of a bearing and the running speed. They can be calculated with the following formulas:[3)]

$$f_c = \frac{1}{60} \cdot \frac{n_i}{2} \left(\frac{d_m - D_a \cdot \cos\alpha}{d_m} \right)$$

$$f_b = \frac{1}{60} \cdot \frac{-n_i}{2} \left(\frac{d_m}{D_a} - \frac{D_a \cdot \cos^2\alpha}{d_m} \right)$$

f_c: Orbital revolution frequency of rolling elements (Hz)
f_b: Rotation frequency of rolling elements (Hz)
n_i: Running speed of inner ring (rpm)
D_a: Diameter of rolling elements (mm)
d_m: PCD of rolling elements (mm)
a: Contact angle (°)

5. Conclusion

We have presented here a summary of the types of vibration and sound in rolling bearings. Among the different kinds of sound and vibration in Table 1, most of them are fairly well understood and the countermeasures explained in this report can be employed to control them when they are deemed excessive. There are still, however, some that are as yet not completely understood. Research is ongoing at NSK in these areas. In any case, it should be understood that, due to the fundamental nature of rolling bearings and limitations on machining technology, a certain degree of vibration and sound is unavoidable.

Vibration and sound generated by rolling bearings is relatively low compared to other machine components. Nevertheless, some customers still request reduced noise. This indicates the pivotal role bearings play in controlling noise generated by machines and probably stems from the fact that sound and vibration can be transmitted from bearings to other parts of a machine and amplified there. For this reason, continued research, not only on bearings, but on their surrounding structures as well, is required.

References:

1)* Noda, "Noise of Rolling Bearings," J. JHPS, 17-7 (1986) 507-513
2)* Igarashi, Noda, "Sound of Ball Bearings," NSK Bearing Journal, 635 (1974) 8-17
3)* Ueno, et al, "Rolling Bearing Engineering," Yokendo Ltd. (1975) 139, 101
4)* Kobayashi, "Grease Effect on Rolling Bearing Sound," J. JSLE, 19-4 (1974) 306-320
5)* Nakai, Yokoi, et al, "Squeal Noise of Cylindrical Roller Bearings," Trans. JSME, C, 56-525 (1990) 1224-1252, 1253-1259
6)* New Product Introduction, "Cylindrical Roller Bearings for Electric Motors with Squeal Noise Countermeasures, NU300U Series," NSK Bearing Journal, 623 (1969) 62
7)* Fujii, "Bearings for Computer Magnetic Disk Spindles," NSK

Bearing Journal, 644 (1984) 14-23
8)* Tamura, et al, “Static Running Accuracy of Ball Bearings,” Trans. JSME, C, 52-475 (1986) 851-858
9) O. Gustafsson, “Study of the Vibration Characteristics of Bearings,” SKF Report, AL 62 L 005 (1962)
10) F. P. Wardle, “Vibration Forces Produced by Waviness of the Rolling Surfaces of Thrust Loaded Ball Bearings,” Proc. IME, 202-C5 (1988) 305-312, 313-319
11) E. Yhland, “A Linear Theory of Vibrations Caused by Ball Bearings with Form Errors Operating at Moderate Speed,” Trans. ASME, J. Tribol., 113-April (1992) 348-359
12)* Kobayashi, Hashimoto, Gotou, “Problems on Rolling Bearing Sound and Vibration (Part 1),” Science of Machines, 20-1 (1968) 19-24
13)* Yamamoto, “Critical Speed of Ball Bearings Regarding Dimensional Errors,” Trans. JSME, 20-99 (1954) 750-755, 755-760
14)* NSK Report No. 457, “Natural Frequency of Bearing Rings (Solid Mode),” Science of Machines, 47-4 (1995) 50
15)* Taniguchi, Endou, “Calculation Method of Annular Ring Vibration,” Science of Machines, 24-2 (1972) 271-275
16)* NSK Report No. 337, “Natural Frequency of Individual Bearing Rings (Part 1),” Science of Machines, 37-4 (1985) 52
17)* NSK Report No. 338, “Natural Frequency of Individual Bearing Rings (Part 2),” Science of Machines, 37-5 (1985) 56

* In Japanese

Tatsunobu Momono

Banda Noda