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THREE-PEAK PHENOMENON IN THE SOUND FIELD OF TRANSONIC AXIAL COMPRESSOR

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ABSTRACT
By means of studying the noise spectra of the isolated rotor compressor and single stage compressor, the middle-peak noise that exists in the *BPF* bandwidth between *SPF* and *BPF* or between two adjacent *BPF* harmonics is observed. Hence, adding two adjacent harmonic peaks, so called three-peak phenomenon occurs within the *BPF* bandwidth. While rotor operates at supersonic tip speed, the three-peak phenomenon becomes much more obviously. The formulas of *BVKF* and its harmonics associated with the middle-peak noise are also presented in this paper. The interval of two neighboring *BVKF* harmonics is *BPF* bandwidth. Besides, the generation mechanism of the middle-peak noise also is preliminarily analyzed and still waits for further quantitatively studies.

1 - INTRODUCTION

The application of high bypass ratio turbofans has considerably reduced the exhaust noise level to such an extent that the emphasis lies on the noise generated by the compressor. The noise spectrum of compressor contains many high peaks of energy at discrete frequencies, which subjectively makes it more annoying than the same level of broadband noise. It is well known that sound sources of compressor primarily involve the interaction noise between rotor and stator and broadband noise at subsonic condition, as well as "buzz-saw" tones or multiple pure tones at supersonic tip condition [1]-[3]. In the cases of different rotating velocity, the in-duct noise measurements have been made at a test facility mounted with an isolated rotor compressor or a single stage compressor. The noise spectra at subsonic and transonic conditions are obtained. By investigating the noise spectra of the single rotor compressor and single stage compressor, the so-called three-peak phenomenon is observed.

2 - TEST FACILITY OF TRANSONIC COMPRESSOR

The experiments are carried out at the testing configuration of transonic axial compressor as shown in Fig. 1. The upper section is single stage compressor, the lower section is single rotor compressor in Fig. 1. The compressor is powered by a free turbine refitted from the A-20A turboprop engine. The maximum rotating speed of free turbine is 12300 rpm which is increased by a gear-up box with a speed increasing ratio around 2. The maximum design rotating speed of compressor is 24000 rpm. The main characteristic parameters of transonic compressor at the test rig are listed as follows. The adjustable range of rotating speed is 8000, 22000 rpm, The tested rotor is a transonic rotor of J-69-T41A Engine. The design rotational velocity is 22000 rpm. The weight flow and the pressure ratio of compressor are 13.5 Kg/s, 1.60 and 0.88, respectively. The rotor tip speed is 409.8 m/s. The relative inlet Mach number at blade tip is 1.404. The relative Mach number at blade root is 0.90. The outer diameter of blade is 355.8 mm hub/tip ratio is 0.565. The chord of blade tip is 81.20 mm aspect ratio is 0.95. The single stage compressor consists of rotor blade number 17 and stator vane number 29. The latter can be displaced 250 mm downstream from the position of rotor so as to investigate the in-duct sound field of a single rotor compressor. The inner diameter of an inlet duct is 356 mm. Because the relative Mach number at blade tip can approach 1.404, therefore this compressor rig can not only simulate the flow field condition of fan engine, but also simulate the actual sound source environment. The axial compressor generates the rotor-stator interaction noise and broadband noise at subsonic condition. In addition, it gives rise to the "buzz-saw" tones while the blade tip speed reaches up to supersonic.

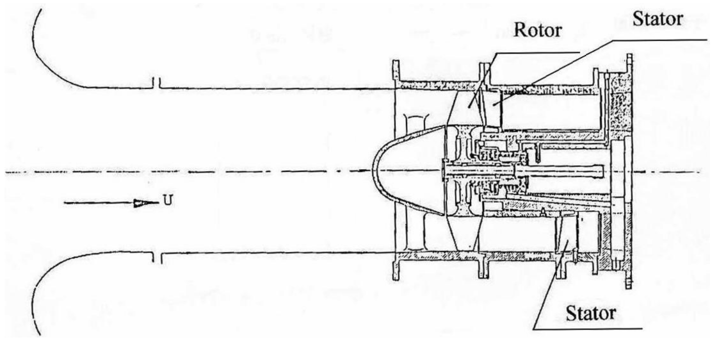

Figure 1: Schematic test facility for single rotor or single stage compressor.

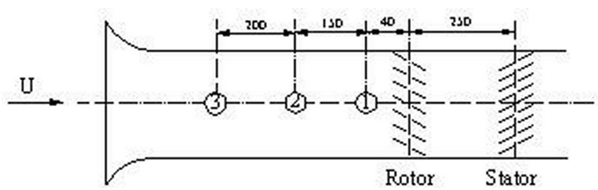

Figure 2: Measuring Schematic of sound field in an inlet duct of compressor.

3 - MEASUREMENTS AND ANALYSIS

The in-duct aeroacoustic experiments are made at the test rig of single rotor and single stage compressor. The three microphones flush with the inner wall of an inlet duct are placed at the positions shown in Fig. 2. The in-duct noise spectra for single rotor compressor at these three microphone positions are shown in Figs. 3 to 11. Figs. 12, 13 and 14 are the in-duct noise spectra for single stage compressor. It must be mentioned that the presence of three inlet struts of cowl in compressor, from which results a circumferential distortion of inlet flow field and interaction with rotor blades and stator vanes, affects the noise level of compressor. With a consideration of the above-mentioned noise spectra of the single rotor compressor as shown in Figs. 3 to 14, it should be especially noticed that the middle-peak noise which exists in the *BPF* bandwidth between shaft passage frequency *SPF* and blade passing frequency *BPF* or between adjacent *BPF* harmonics is found. Hence, in view of additional two adjacent harmonic peaks, the so-called three-peak phenomenon occurs within the *BPF* bandwidth, as shown in Figs. 3 to 14. If it can be said from Figs. 3, 4 and 5 that the three-peak phenomenon at subsonic condition doesn't occur evidently, then while rotor operates at supersonic tip speed, the three-peak phenomenon becomes much more obviously, as shown in Figs. 9 to 14. Here, the frequencies corresponding to the middle-peak tones are named for $BVKF$ and its harmonics. It could be interestingly found from their noise spectra that the relative position of $BVKF$ of each order between its left-side and right-side adjacent *BPF* harmonics is not changed at a given rotating speed. Furthermore, the interval of two neighboring $BVKF$ harmonics is found to be *BPF* bandwidth. At the $BVKF$ and its harmonics, not only the discrete tones occur, but also the broadband "white" noise is increased. In addition, the middle peak noise still has a significant influence on the noise of the farfield. Therefore, the effects of the middle-peak noise on the overall noise level of compressor can't be ignored. The predicting formulas of $BVKF$ and its harmonics are presented as below. For the operating condition with a given rotating speed in the frequency range of $(n-1)\times BPF$, $n\times BPF$, n=1, 2, 3,..., while n=1, $(n-1)\times BPF$ namely is *SPF*, the $BVKF$ of each order can be calculated as follows

$$n \times BPF - nBVKF = K \times \frac{B+V}{B} \times SPF \tag{1}$$

$$nBVKF - (n-1)\,BVKF = BPF \tag{2}$$

Where B is number of rotor blades, V is number of stator vanes, K is number of the struts of cowl. The n among the $nBVKF$ is not multiplied with $BVKF$, but represents the order of $BVKF$. Eq. (1) indicates that, the $BVKF$ of various orders must not be the multiple of the shaft passing frequency, which depends on whether the value of $K \times (B+V)/B$ is an integral. For the test rig of compressor, K=3, B=17, V=29. Thus the $BVKF$ of each order is not the multiple of shaft passing frequency SPF. Just for this reason, the presence of $BVKF$ and $2BVKF$ between two contiguous harmonics of SPF can be observed in Fig 9. Such conclusions and Eq. (1) and (2) have been verified in the other measurements of noise spectra for both single rotor and single stage compressor. The doomed occurrence of the middle-peak noise in BPF bandwidth certainly implies a particular aeroacoustic mechanism. With a view of obtaining a reasonable explanation for this phenomenon, authors think that the unsteady interactions between the struts of cowl and rotor blades as well as stator vanes should be synthetically studied, rather than investigated separately. The inlet supporting struts or other similar obstructions such as the inlet guiding vanes cause a circumferential distortion in the inlet flow. The wake flows behind the struts cause fluctuation in the aerodynamic forces on blades as they pass through. The generation mechanism of the middle-peak noise probably deals with the transmission and multi-interaction of unsteady airflow wakes between struts of cowl or inlet guiding vanes and rotor-stator blades. Consideration of the effects of penetration due to multiple wakes between struts, rotor blades and stator vanes would be helpful to understanding the occurrence of three-peak phenomenon. The generation mechanism of the middle-peak noise generated from compressor is ready to be further quantitatively studied.

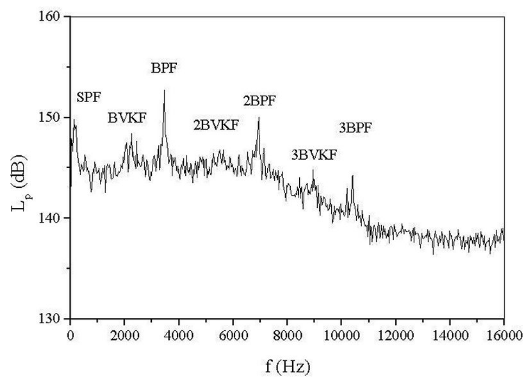

Figure 3: n=12045 rpm, spectrum of mic.1.

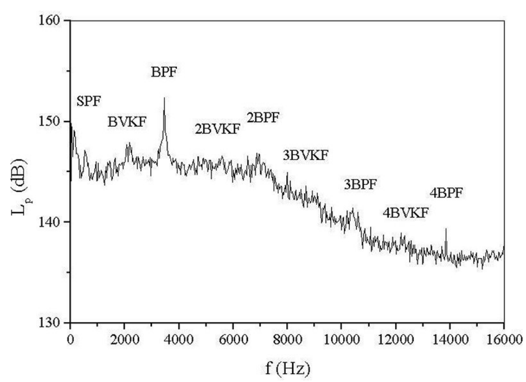

Figure 4: n=12045 rpm, spectrum of mic.2.

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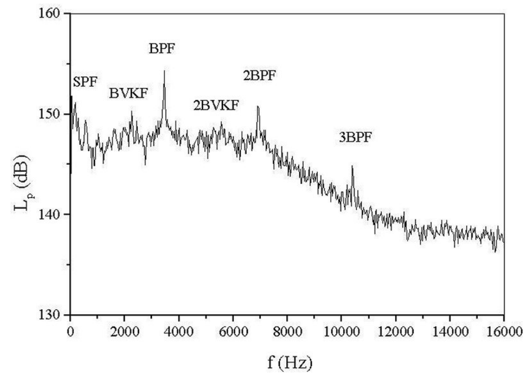

Figure 5: n=12045 rpm, spectrum of mic.3.

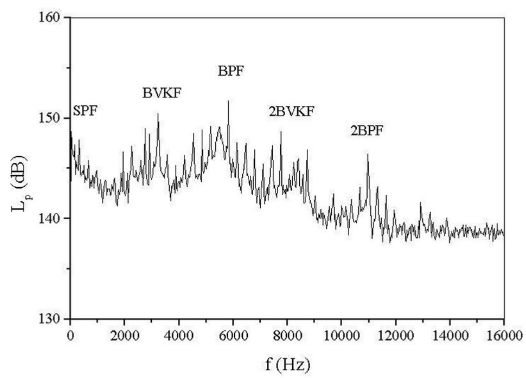

Figure 6: n=19022 rpm, spectrum of mic.1.

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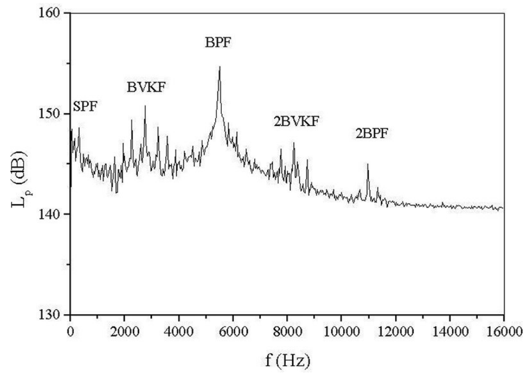

Figure 7: n=19022 rpm, spectrum of mic.2.

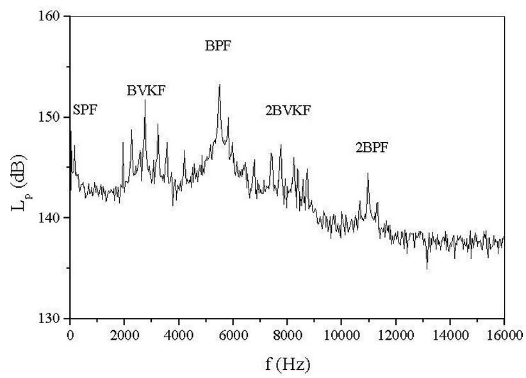

Figure 8: n=19022 rpm, spectrum of mic.3.

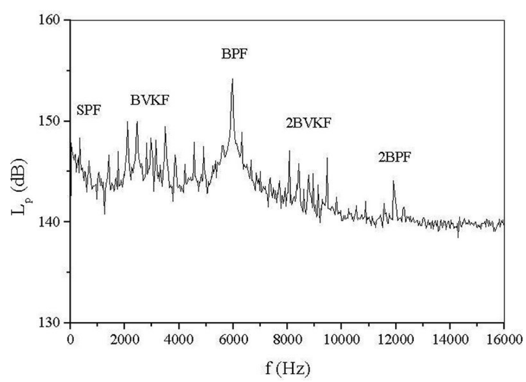

Figure 9: n=20714 rpm, spectrum of mic.1.

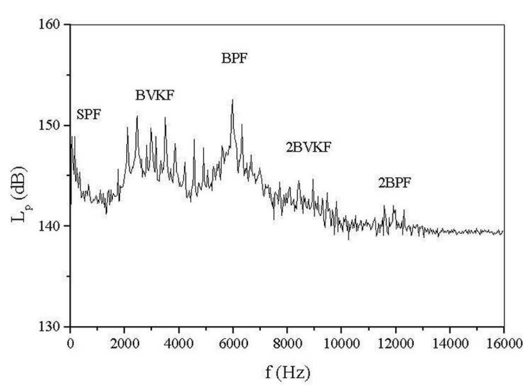

Figure 10: n=20714 rpm, spectrum of mic.2.

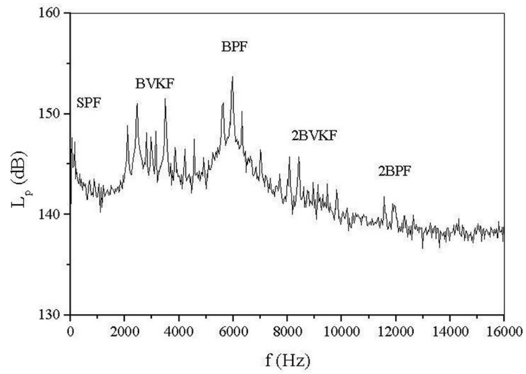

Figure 11: n=20714 rpm, spectra of mic.3.

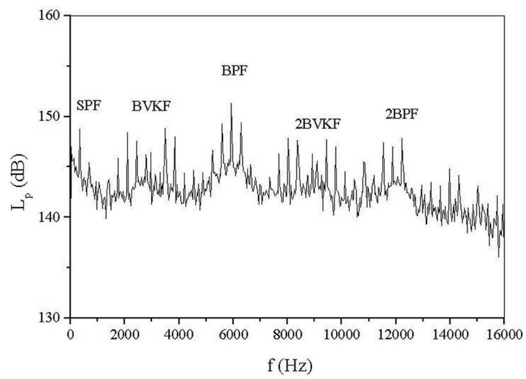

Figure 12: n=20500 rpm, spectra of mic.1.

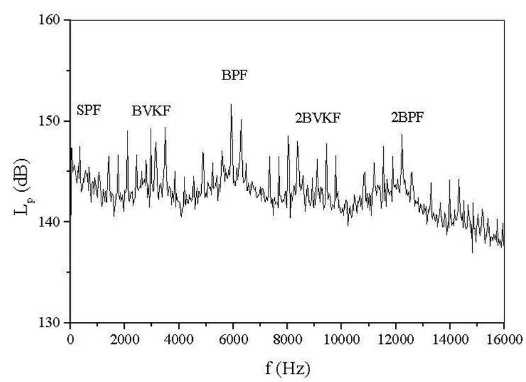

Figure 13: n=20500 rpm, spectrum of mic.2.

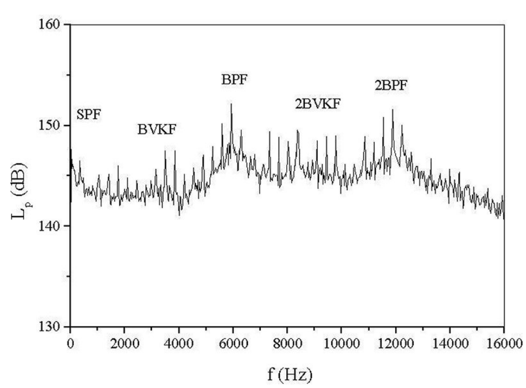

Figure 14: n=20500 rpm, spectrum of mic.3.