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Electrical and Mechanical Noise Study of the 765kV Transmission Line

765 kV 송전선로의 전기적 및 기계적 소음 고찰

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ABSTRACT

If the transmission line voltage is greater than 500 kV, audible noise (AN) and hum noise (HN) due to corona discharges on the conductor would be an important design factor for the conductor selection of transmission line. Also there is an aeolian noise : wind noise (WN) from the tower and the conductor due to wind. This paper presents the results of a statistical analysis of audible noise, hum noise, aeolian noise of 6-480 mm² conductor bundle in KEPRI 765kV Test Transmission Line which was constructed to develop 765kV double circuit AC transmission line for the first time in the world. The result of the analysis shows that 6-480 mm² conductor bundle and tower satisfy configuration the audible noise design criterion of 50dB(A).

요 약

송전전압이 500kV 이상이 되면, 송전도체의 코로나 방전에 의해 발생하는 가청소음, 험소음이 송전선로의 도체 선정에 중요한 요소가 되며 또한 바람에 의한 철탑과 도체의 풍소음도 발생한다. 본 논문은 세계최초로 765kV 2회선 교류 송전선을 개발하기 위해 건설한 한전 전력연구원 765kV 시험송전선로의 상당 480mm² 도체 6가닥으로 구성된 송전선 구성에서 가청소음, 험소음, 풍소음의 통계적인 분석결과를 나타내었다. 분석결과를 보면 6-480mm² 도체와 철탑구성이 가청소음 설계목표치인 50dB(A)를 만족함을 알 수 있다.

Nomenclature

AN : Audible Noise
ANSI : American National Standards Insti-

tution
HN : Hum Noise
BPA : Bonneville Power Administration
WN : Wind Noise
Apple Grove : GE Research project
RI : Radio Interference
Hydro-Quebec : Canada Electric Utility
TVI : TV Interference

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1. Introduction

KEPRI has studied to develop a 765kV double circuit line to meet the need for economical bulk power transmission over the limited right-of-way with the least environmental impact to the people who live in the near-by the transmission line since 1984.

At the first stage of the study after the preliminary design of the line, the corona performance tests were conducted in a corona cage which simulates the average maximum bundle gradient of a 765kV transmission line in a low voltage with a test transformer and artificial rain facilities. After the audible noise measurement of 8 kinds of conductor bundle in the corona cage, KEPRI has found that a bundle of 6-480 mm² conductors is the minimum one to meet the audible noise design criterion of 50 dB(A) and any large 4-conductor bundle can not meet the criterion of 50 dB(A). KEPRI tentatively selected the 6-480 mm² conductor as the conductor of a 765kV transmission line in Korea⁽¹⁾.

In the long term transmission planning, two routes of 765kV line are scheduled to build by the end of

1998. In 1989, before the decision of the upgrading the system voltage of 345kV to 765kV KEPRI decided to build a full scale test line with a bundle of 6-480 mm² conductors to compare with the result of the simulation(corona cage)test and to evaluate the environmental impact of corona in the vicinity of a 765kV transmission line and electrical & mechanical performance of the localized equipments prior to the start of the commercial line design. The test line is located in the southwest coast in Korea peninsula

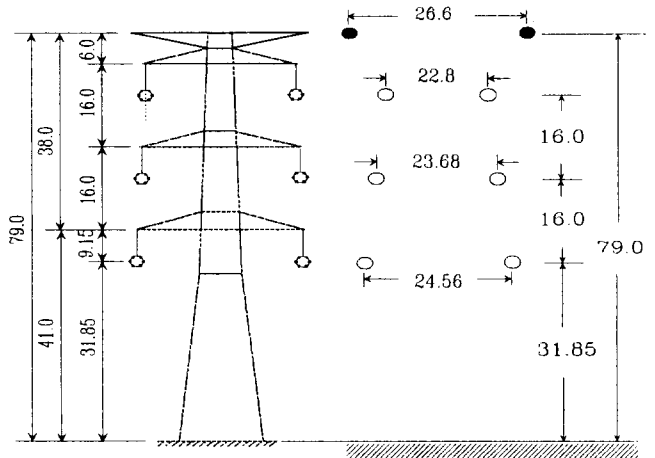


Fig. 1 The configuration of a suspension tower in the line

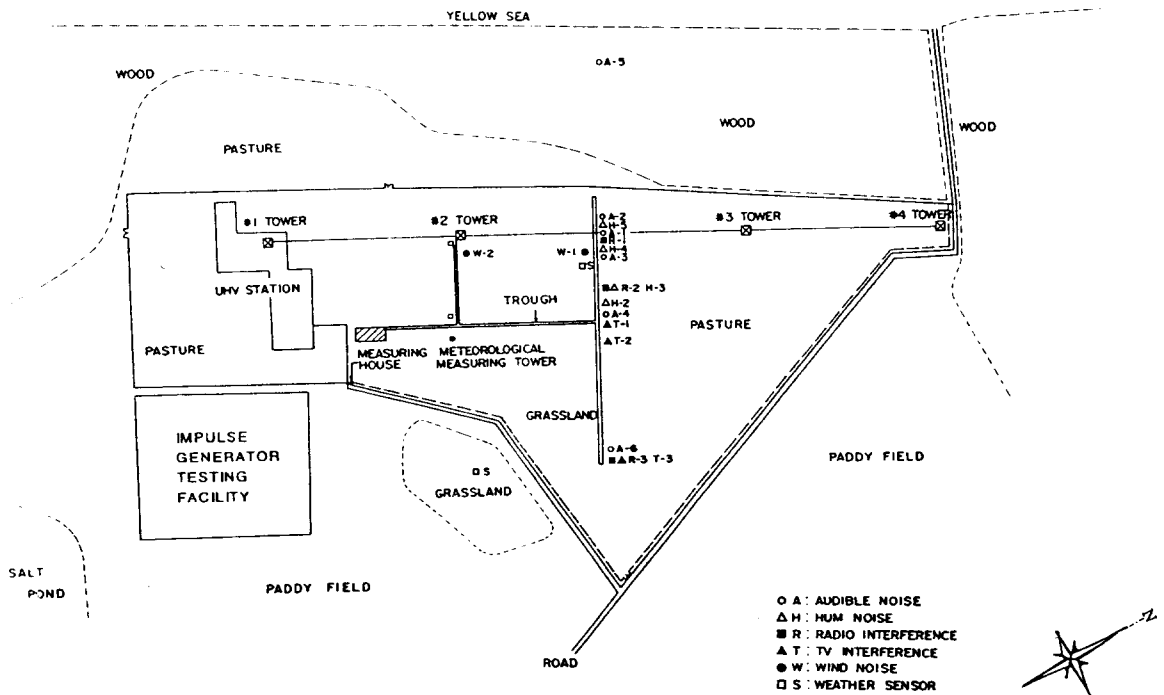


Fig. 2 The physical layout of Kochang 765kV test line

and has been operated in 765kV since April, 1993. The data measured at test line on a long term basis are audible noise (AN), hum noise (HN), radio interference (RI), TV interference (TVI), aeolian noise; wind noise (WN) and electric field intensity (EF) at 1m above the ground level. These data have been automatically recorded under the various weather conditions since August 1993. In this paper, the analyses of electrical noise (audible & hum noise) and mechanical noise (aeolian noise) are presented.

Kochang 765kV Full Scale Test Line

Kochang 765kV test line was designed as a full scale double circuit transmission line in the electrical and mechanical strength. The tower geometry and the number of the insulator discs were designed to demonstrate a actual 765kV double circuit line in general area. Because the test line is located near the seaside, the frequent cleaning of the insulator strings is prerequisite.

Figure 1 shows the geometry of a suspension tower in the test line and conductor height in the tower. The spacing of the subconductors is 40cm which gives the minimum surface gradient on the conductors. The test line consists of two dead end towers, two suspension towers and three spans. The span lengths are 200, 300 and 200m respectively. Three 3MVA 23/765kV single-phase transformers energize the test line. The voltage of the test line is controlled by a 1500kVA on-load tap changing transformer. Most of the measurement sensors are installed transversally in the middle of the midspan as Fig. 2 in the relatively flat terrain⁽⁶⁾.

2. Instrumentation And Data Recording

The acquisition data from the sensors located in the midspan, meteorological towers, rain gauge and capacitor voltage transformers have been recorded on line by DEC workstation. The scanning interval is 3 minutes. The weather data include wind speed and direction, relative humidity, temperature, barometric pressure, rain rate and so on.

All kinds of sensors for AN, HN, WN, RI and TVI are installed along the lateral direction in the middle of the midspan and connected to the measuring instruments in the measuring room by long coaxial cables. To measure AN, B & K type 4184 1/2 inch weatherproof microphone units are located at 0 (AN1: reference point), 15 (AN3: evaluation point), 60 (AN4), and 178m (AN6: ambient noise) respectively from the ground level point directly under the outmost phase conductors along the lateral direction in the middle of the midspan as shown in Fig. 2. The noise level analyzers, B & K type 4435 have been used to measure the corona noise via B & K type 4184 microphone units. Even though the microphones are covered with windscreens, to minimize wind-generated noise the 0.34m of AN and HN microphones height is adopted instead of 1.5m in ANSI standard.

3. The Result of Data Analysis

The long term measured data from August, 1993 to March, 1995 have been statistically analyzed to evaluate the environmental impact due to the corona phenomena of the test line. Especially the AN and HN analysis of the rainy weather condition was emphasized. The test results were compared with the predicted value and the simulated results in the corona cage. Table 1 shows the number of raw data and effective data. The only effective data were used in each analysis.

3.1 Electrical Noise

Audible Noise

If the measured audible noise data are satisfied with the following conditions, the data are defined as

Table 1 Effective data acquisition rate

Items	No. of raw data		No. of effective data (Acquisition rate)	
	Fair	Rainy	Fair	Rainy
AN	158,902	5,831	83,429 (52.5%)	3,198 (54.8%)
HN	134,037	4,468	113,864 (84.9%)	3,994 (89.4%)
WN	138,505		24,511 (17.7%)	

effective data. Namely the other data would be discarded.

- a) Wind velocity should be less than 5m/s
- b) Test voltage should be within $\pm 1.5\%$ tolerance
- c) The measured value should be greater than the ambient noise level (ANL) by 4dB (A)

Then the effective AN data are corrected according to IEEE Std. 656-1992, KSA0701-1987 and JIS Z8731-1983 as following⁽⁶⁾.

- a) If $AN - BGN \geq 10dB(A)$, then $AN = AN$
- b) If $6 \leq AN - BGN \leq 9$, then $AN = AN - 1$
- c) If $4 \leq AN - BGN \leq 5$, then $AN = AN - 2$

These correction criteria prevent the measured data from mixing with the data of high ambient noise and extraneous induced wind noise. The AN probability distributions of AN3 under the rainy weather condition is shown in Fig. 3. It was analyzed that the measured value of audible noise L_{50} in stable rain is very close to the predicted program and higher than the value of the corona cage by 3.9 dB (A). We think that the 3.9dB(A) difference results from the difference between artificial rain rate in corona cage and natural rain rate in test line.

Audible Noise Frequency Spectrum

Figure 4 shows the characteristic shape of the 1/3 octave band acoustic noise spectra of the test line

during fair and rainy weather condition and illustrates the influence of humidity (rain) which will be examined again in the following paragraph by the rainfall intensity. It was observed that the higher part of the audible noise frequency spectrum is formed by frequency components between 80 Hz and 10,000 Hz, taking into account audible noise produced by the corona generated on the conductor in rainy weather condition. The spectral distribution is relatively dependent on the meteorological conditions such as rainfall intensity, humidity etc.

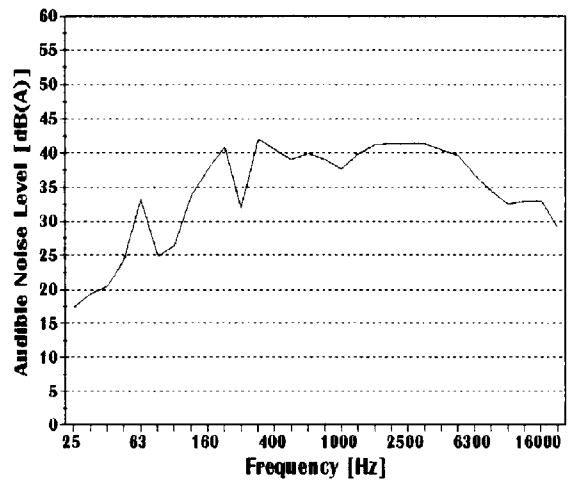


Fig. 4 Characteristic spectrum of the AN

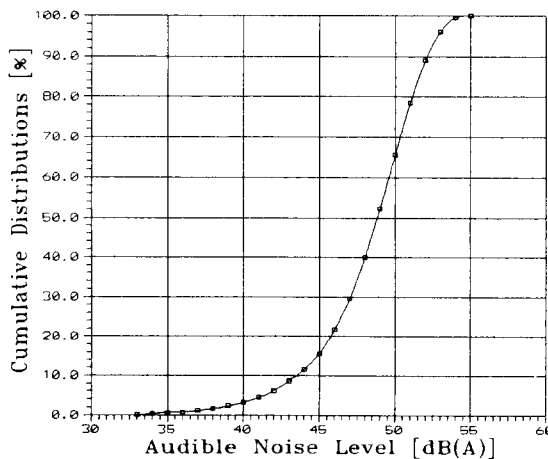


Fig. 3 AN cumulative distribution of AN3 in rain

Table 2 Comparison of measured and predicted A-weight AN at the 15m from the outmost phase

Weather	Measured		Predicted * BPA [dB(A)]
	Test line [dB(A)]	Corona cage [dB(A)]	
Stable rain L_{50}	48.8	44.9	48.5
Heavy rain L_5	52.8	52.2	52.0
Fair L_{50}	42.1	42.7	23.5

* Predicted equation of BPA [dB(A)]

$$AN = 120 \log g + K \log n + 55 \log d - 11.4 \log D + AN_0$$

here, $g = G_{max}$ of bundle

$$K = 26.4 \text{ for } n \geq 3$$

$$AN_0 = -128.4 \text{ for } n \geq 3$$

d = Diameter of Conductor

D = Distance between Source and Mic.

n = Number of Conductor

The Influence of Rainfall Intensity

The relationship between rainfall intensity and audible noise is summarized in Table 3 and plotted in Fig. 5. The total effective AN data in rainy weather were analyzed 5% and 95% cumulative distribution of audible noise(AN3) is 41.3 dB(A) and 52.8 dB(A) respectively. The same distribution of ambient noise level by AN6 microphone is 30.3 dB(A) and 48.1 dB(A) respectively. It is noteworthy that the difference between 5% and 95% distribution of AN3 is 11.5 dB(A) however the difference of AN6 is 17.8 dB(A).

The difference between AN3 and AN6 in 95% is only 4.7dB, therefore this would indicate that in the higher rainfall intensity weather condition, generally over than around 6.6mm/hr, the resident near the transmission line feel the lower nuisance of corona noise due to high ambient rainfall noise. On the other hand it is observed that there is a saturation effect of audible noise at about 30 mm/hr rainfall intensity from test line and corona cage measurement.

Lateral Profiles of Audible Noise

The attenuation phenomena of audible noise as a function of the lateral distance between microphones and tower center is plotted in Fig. 6. The L_{50} (rain) noise level decreases by 5 dB(A) approximately each time the distance is doubled. However the L_{50} (fair) sound level decreases by 2.5 dB(A). Even though there is about 2.5 dB(A) difference between L_{50} (rain) and L_{50} (fair), this result is nearly same as the results that the A-weighted attenuation is between 3 and 4 dB per doubling of radial distance, derived from BPA, Apple Grove, and Hydro-Quebec⁽⁴⁾.

The attenuation can be due to atmospheric absorp-

Table 3 Characteristic AN data of rainfall intensity

		Exceed level[%]					
		5	25	50	75	95	99.9
Rainfall intensity [mm/hr]		0.1	0.5	0.9	2.3	6.6	31.9
Audible noise [dB(A)]	AN3	41.3	46.4	48.8	50.7	52.8	55.0
	AN6	30.3	39.2	42.2	44.9	48.1	52.0

tion, refraction, shielding, ground interference, and scattering etc.

Hum Noise

The audible noise of transmission lines in corona

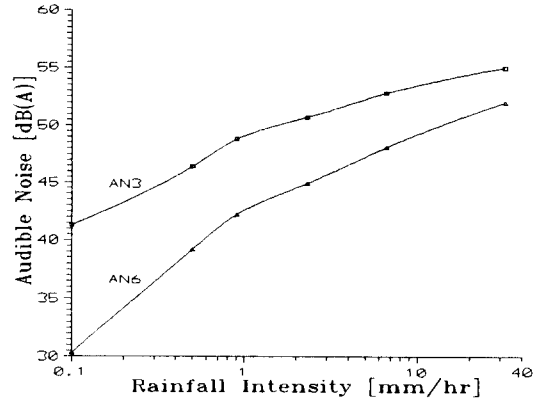


Fig. 5 AN characteristic curve on rainfall intensity

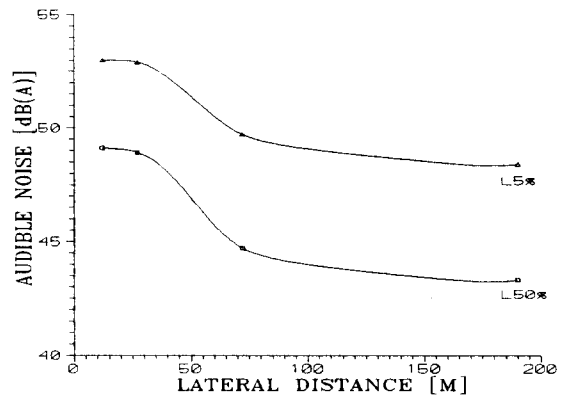


Fig. 6 Lateral profiles of Audible Noise in KEPRI 765kV double circuit test transmission line

Table 4 Lateral profile data

Mic. No.	Lateral dist. from the refer. point [m]	Mean radial distance from microphone to cconductors [m]	Rainy weather [dB(A)]				Equivalent rainfall intensity [mm/hr]		Fair weather [dB(A)]	
			L_5	L_{25}	L_{50}	L_{75}	R_5	R_{50}	L_5	L_{50}
AN1	0	52	53.0	50.9	49.2	46.7	6.6	0.9	51.2	41.9
AN3	15	58	52.8	50.7	48.8	46.4			51.5	42.1
AN4	60	88	49.6	46.9	44.7	42.5			48.9	39.9
AN6	178		48.1	44.9	42.2	39.2			46.6	38.9

includes a 120-Hz hum. The hum is especially noticeable in heavy rain, ice and wet snow. The 120-Hz hum is only slightly attenuated by air, trees, and walls. Therefore, its importance might be greater than that of audible noise at larger distances from the line or inside houses.

The average hum noise level (L_{50}) in the rainy weather at 18m from the reference point is 47.1 dB and this value is equivalent to 30.5 dB(A) in time averaging (L_{ti}) and to 31.8 dB(A) in spacing averaging value (L_s). A L_s was calculated from equation (1)⁽⁸⁾. The typical frequency spectrum of HN in rainy weather is shown in Fig. 4

$$L_s = 10 \log \left\{ \frac{\sum_{i=1}^N (10^{\frac{L_{ti}}{20}})^2}{N} \right\} \quad [\text{dB}] \quad (1)$$

where L_{ti} : L_{t50i} at i th measuring point
 N : Number of measuring points

3.2 Mechanical Noise

Aeolian Noise

Only two microphones are used for measurement of aeolian noise. $W1$ microphone which is located at midspan, is used for conductor noise measurement and $W2$ microphone which is located in front of #2 tower, is used for tower noise measurement. Two anemometers are mounted on the arms of #2 tower 41m, 73m above ground respectively. The wind velocity for aeolian noise analysis is assumed as the average wind velocity from the two meters.

Domain frequencies of conductor and tower aeolian noise is around 50 and 100 Hz respectively as shown in Fig. 7 and Fig. 8. The aeolian noise value, 64.9dB(C), at tower side is higher than, 61.2 dB(C),

Table 5 Measurement data of aeolian noise

	Conductor side (W1) [dB(C)]	Tower side (W2) [dB(C)]	Wind velocity [m/s]	Wind direction [°]
$L_5\%$	77.8 (49.8dBA)	82.4 (63.4dBA)	13.2	84.1
$L_{50}\%$	61.2 (33.2dBA)	64.9 (45.9dBA)	7.3	53.7
Band	40~90	45~97	5~20	0~90

that of conductor side noise. $W1$ and $W2$ aeolian microphones included C-weighting filters owing to impulsive characteristics of aeolian noise. These C-weighting values of tower and conductor side are equivalent to 33.2 and 45.9 dB(A) by equation (2)⁽⁸⁾. The average wind speed and wind direction in this

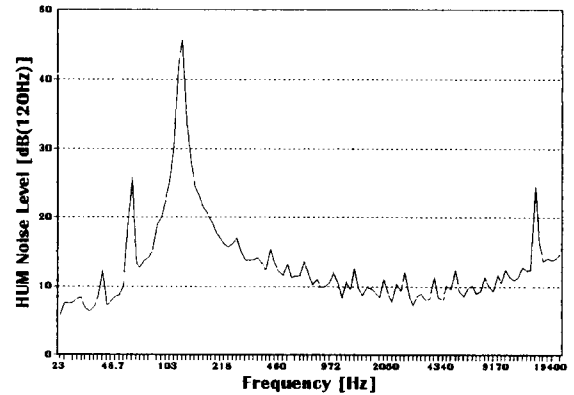


Fig. 7 HN frequency spectrum in rainy weather

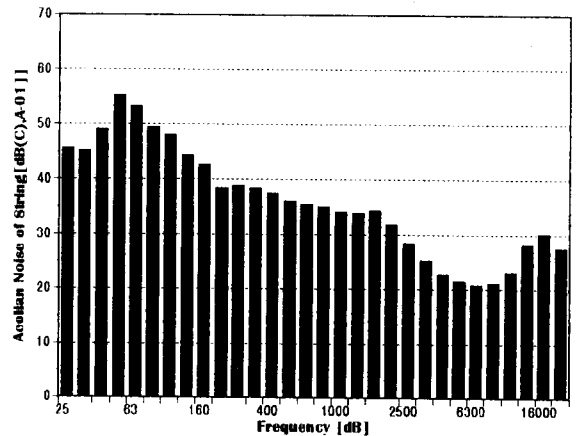


Fig. 8 A frequency spectra of conductor aeolian

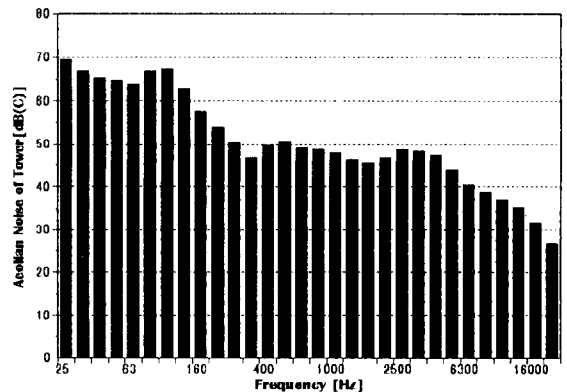


Fig. 9 A frequency spectra of tower aeolian noise

measurements was 7.3m/s and 53.7°, respectively.

$$V_A[\text{dB(A)}] = V_M[\text{dB}] + 30 \log f - 79 \quad (2)$$

where,

- V_A [dB(A)] : Converted A weighting value
 V_M [dB] : Measured with C weighting value
 f : Dominant frequency ($\leq 250\text{Hz}$)

5. Discussion and Conclusions

Electrical noise and mechanical noise of 765kV transmission line were measured and analyzed by Kochang 765kV transmission test line. On the basis of observations described above, the following conclusions are drawn from the long-term study on the noise level of 765kV transmission line.

- (1) The L_{50} audible noise of 6-Rail conductor bundle in the rainy weather at 15m from the outmost phase is 48.8dB(A) and in the fair weather is 42.1dB (A). This conductor bundle and tower satisfy the design criteria of 50dB(A).
- (2) The L_{50} hum noise in the rainy weather is 47.1 (31.8)dB(A) and the L_{50} wind noises of conductor side & tower side are 33.2 dB(A), 45.9 dB(A) respectively.
- (3) Hum noise and aeolian noise seem like no problem because the hum noise and the L_{50} hum noise and the L_{50} aeolian noise is lower than L_{50} audible noise in rainy weather.
- (4) The increasing rate of audible noise below nominal voltage (765kV) is much lower comparing to the rate above nominal voltage. Therefore we know that system operating voltage of 6-Rail conductor bundle must be maintained not to exceed the nominal voltage in order to suppress the audible noise.

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