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DAMPING COEFFICIENTS OF Q-TYPE BURSTS IN THE SCHUMANN RESONANCE FREQUENCY RANGE

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Abstract

Simultaneous measurements of electric and magnetic components of natural ELF electromagnetic noises were made. Damping coefficients of Q-type bursts were estimated from their waveforms for the fundamental mode of Schumann resonances. It is found that the damping coefficient of the bursts of NS propagation component is larger by 29% on the average than that of EW propagation component, mean values being 6.27, and 4.87 sec^{-1} respectively, while the electric vertical component has the value of 4.96 sec^{-1} The attenuation constant, and the Q factor of the earth-ionosphere cavity were discussed based on these values of damping coefficients, comparing with the values obtained by the previous investigation.

1. Introduction

It was first postulated by Schumann [1952 a, b] that lower ELF electromagnetic waves resonate in the spherical cavity bounded by the ionosphere and the earth. Since then many experimental investigations on Schumann resonances have been made, notably by Balser and Wagner [1960] who first clearly detected the resonances.

On the theoretical bases, assuming that the upper boundary of the cavity is the sharply bounded, homogeneous, and isotropic ionosphere which is infinite in extent, Wait [1960] pointed out that a waveform of the electric vertical field excited by a dipole source of step function is given approximately by $e^{-\Omega_n t}\cos\omega_n' t$, where $\Omega_n=\frac{1}{h}\sqrt{\frac{\omega_{on}}{8\mu_0\sigma_i}}$, $\omega_{on}=2\pi f_{on}$ and $f_{on}=f_n'+\frac{\Omega_n}{2\pi}$ f_n' is the resonant frequency, f_{on} the calculated resonant frequency with the perfectly conducting ionosphere (10.6 Hz), Ω_n the damping coefficient, h the height of the ionosphere, σ_i specific conductivity of the ionosphere, and μ_0 permeability of free space. Based on this theory, damping coefficients were estimated from the observed fundamental mode frequency by Rycroft and Wormell [1964], and from the observed second mode frequencies in undisturbed and disturbed conditions at an occurrence of the solar flare on July 7, 1966 by Ogawa et al. [1966 a].

It is, however, possible to estimate a damping coefficient directly from a wave-

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form. Ogawa et al. [1966 b] divided the observed lower ELF natural noises into three different characteristic types according to their amplitudes and waveforms; ELF flash, ELF burst (N-and Q-types), and ELF continuous. The Q-type burst is of special interest in these three types, the waveform showing an exponentially damping oscillation of about 8 Hz (the observed fundamental mode frequency in the Schumann resonances) from which the damping coefficient can be estimated.

In the present investigation, the simultaneous measurements of five components of lower ELF noises were made for about 4 minutes every hour on December 28–29, 1968, at Aso Volcanic Laboratory. The five components are the electric vertical, horizontal NS, and EW components, and the magnetic NS, and EW components. The damping coefficients were estimated for each component.

2. Instrumentation

The details of the instrumentations of electric components used for the present investigation are described in the other papers [Ogawa et al., 1966 b, 1969]. The magnetic components were observed by the use of induction coils with high permeability cores. Each receiving coil consists of 120,000 turns of isomel insulated wire of 0.26 mm in diameter wound over a length of 800 mm on a bakelite tube. High permeability cores consist of a 15 $\times$ 15 $\times$ 1,500 mm stack of 0.5 mm laminations. The frequency responses of the whole system of the measuring apparatus are level within $\pm$1.5 db from 5.6 to 32 Hz for the magnetic components and from 3.8 to 28 Hz for the electric components.

3. Data analysis

An example of the observed waveforms is given in Fig. 1, in which V_T is the electric vertical component, E_{NS} the electric NS component, E_{EW} the electric EW component, H_{NS} the magnetic NS component, and H_{EW} the magnetic EW component respectively. The recording pens ran at a speed of 50 mm/sec. The waveforms of NS propagation components (E_{NS} and H_{EW}) are the same as each other by turning one of them upside-down. The waveforms of EW propagation components (E_{EW} and H_{NS}) have the same relation. It is clearly seen that a Q-type burst occured at 19h01m03.9s and continued for about 0.78 sec. The damping coefficient of the event was estimated by the following procedure; a time series of successive double peak amplitudes and halves the average period of oscillation of the event were read and plotted in a semi-logarithm graphic paper for each component. Then the damping constants were calculated with the method of least squares. The result gives the values of 2.4$\pm$0.21, 5.6$\pm$0.30, 4.7$\pm$0.34, 4.5$\pm$0.16, and 6.2$\pm$0.29 sec^{-1} for the components V_T, E_{NS}, E_{EW}, H_{NS}, and H_{EW} respectively. The damping constants of E_{NS} and H_{EW} differ by 10.7% from each other, and those of E_{EW} and H_{NS} differ by 4.4% from each other. These differences probably came from reading errors. The same calculations were

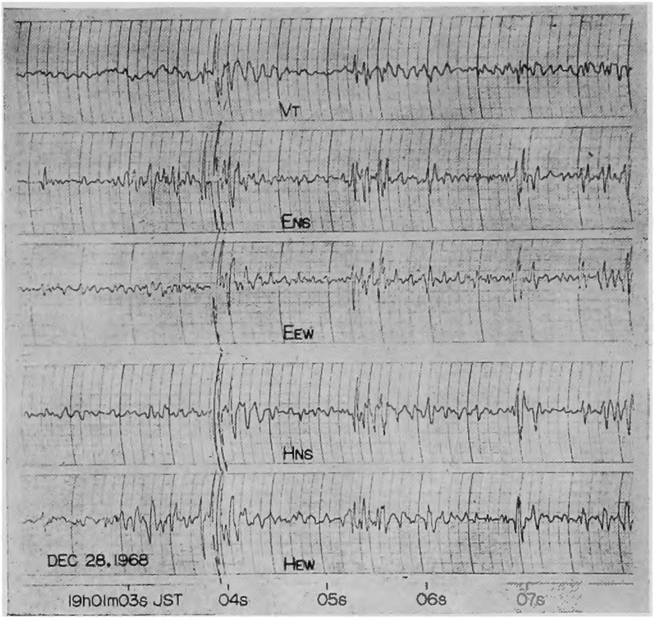

Fig. 1. An example of lower ELF band waveforms recorded at Aso on December 28, 1968. A Q-type burst occured at 19h0lm03.9s.

V_T: electric vertical component
E_{NS}: electric horizontal NS component
E_{EW}: electric horizontal EW component
H_{NS}: magnetic horizontal NS component
H_{EW}: magnetic horizontal EW component

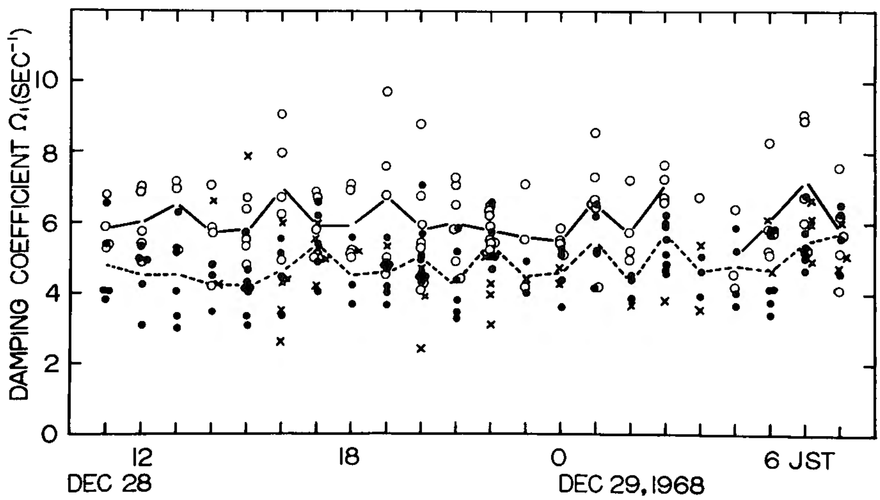

Fig. 2. Damping coefficients estimated from NS propagation components (E_{NS} and H_{EW}: open circle), EW propagation components (E_{EW} and H_{NS}: closed circle), and electric vertical component (V_T: cross). Mean values of each hour are connected by solid and dashed lines for NS and EW propagation components respectively.

made for the other bursts, the number of which is 10% of all data. Probable errors were found to be less than 10% in those calculations, so that a simple method of graphic analysis was used for the rest of data.

The damping coefficients thus estimated of the three components for each hour are given in Fig. 2. The open circle gives the damping coefficient of NS propagation components (E_{NS} and H_{EW}), the closed circle gives that of EW propagation components (E_{EW} and H_{NS}), and the cross gives that of electric vertical component (V_T). Mean values of each hour are connected by solid and dashed lines for NS and EW propagation components respectively. The numbers of data used for this estimation are 99, 113, and 37 for the NS, EW, and vertical components respectively.

5. Discussions

It is interesting to see in Fig. 2 that the damping coefficients of NS propagation component are generally larger than those of EW propagation component by about 29% on the average, though differences between both values change with the lapse of time. The mean values of the coefficients are 6.27 and 4.87 sec^{-1} for the components of NS and EW propagation respectively, the values varying from 3.0 to 9.7, while the electric vertical component has the mean value of 4.96 sec^{-1}.

That the damping coefficient of the NS propagation component is larger than that of the EW propagation component, means the difference of the attenuation constants. This may be caused by anisotropy of the upper boundary of the earth-ionosphere cavity due to the earth's magnetic field, and by inhomogeneity along the wave propagation pass in the ionosphere, of which conductivity profile as a function of altitude in the day side is different from that in the night side.

The attenuation constant α_n (db/Mm) can be calculated from the damping coefficient by the relation α_n (db/Mm)$=4.343 \times 10^6\ \Omega_n/v_{ph}$, where v_{ph} is the phase velocity. Assuming $c/v_{ph}=1.35$ at 8.0 Hz calculated by Jones [1967] with the whole profile of Cole and Pierce [1965], the attenuation is estimated 0.194 db/Mm from the damping coefficient 4.96 of the electric vertical component, which is in good agreement with the attenuation 0.22 obtained theoretically by Jones.

In general, a free oscillation in a cavity resonator with its walls of finite conductivity is expressed by const$\cdot e^{j\omega t}$, where $\omega=\omega_0\sqrt{1-\left(\frac{1}{2Q}\right)^2}+j\frac{\omega_0}{2Q}$. ω_0 is the resonant angular frequency in a perfectly conducting cavity and Q the quality factor which gives sharpness of the resonance. Then $e^{j\omega t}=e^{-\frac{\omega_0}{2Q}t}\ e^{j\omega_0\sqrt{1-\left(\frac{1}{2Q}\right)^2}\,t}$.

Thus the Q is related with the present damping coefficient by $Q=\frac{\omega_0}{2\Omega}$. Using the values of the damping coefficients obtained here, Q factors are estimated 5.32, 6.85, and 6.72 for the NS propagation component, the EW propagation component, and the electric vertical component.

The Q factor is also estimated by means of alternative definition given by the ratio of the resonant frequency ω' to the interval between the frequencies $2\Delta\omega'$ for which the power is equal to half its resonant value. This was recently done by Ogawa and Tanaka [1970] by using a sonagraph. They give the value of 3.3 for the fundamental mode of the electric vertical component, which is about half the value obtained here. The reason of this discrepancy is the following. The latter definition holds only when $\Delta\omega'/\omega' \ll 1$. However the Q factor of the real earth-ionosphere cavity is so small that it does not satisfy this condition. Therefore the Q factor estimated by the method of taking half power band width does not give real Q of the cavity.

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