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A RING CORE FLUXGATE MAGNETOMETER FOR IEEY PROGRAM IN BRAZIL

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A three component ring core fluxgate magnetometer was constructed to record geomagnetic daily variations in the Brazilian Equatorial Electrojet Region during the IEEY (International Equatorial Electrojet Year) period. The ring core sensor and electronic circuits of the magnetometer are accommodated in a PVC tube with a diameter of 20 cm and height of 35 cm. The magnetometer has three analog outputs of ± 5 volt or ± 1000 nanoTesla corresponding to the H, D and Z components. It has a precision better than 1.0 nanoTesla. The magnetometer showed an acceptable performance in monitoring the daily variations in the H, D and Z components of the geomagnetic field.

Key words: Ring core fluxgate; IEEY Program; Fluxgate magnetometer.

UM MAGNETÔMETRO FLUXGATE DE NÚCLEO SATURADO PARA O PROGRAMA IEEY NO BRASIL*: Um magnetômetro de três componentes do tipo núcleo saturado em forma de anel foi construido para registrar as variações diurnas geomagnéticas durante o periodo de IEEY (Ano Internacional do Eletrojato Equatorial) na região brasileira do Eletrojato Equatorial.*

O sensor de anel e os circuitos eletrônicos do magnetômetro foram acomodados num tubo de PVC de diâmetro ~20 cm e altura 35 cm O magnetômetro tem três saídas analógicas de ±5 volts equivalente a ±1.000 nanotesla, correpondentes aos componentes H, D e Z. Ele tem precisão melhor que 1 nanotesla. O magnetômetro tem mostrado funcionamento aceitável para monitorar as variações diurnas dos componentes H, D e Z do campo magnético.

Palavras-chave: *Fluxgate de núcleo saturado; Programa IEEY; Magnetômetro fluxgate.*

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INTRODUCTION

Temporal changes in the intensity of the Earth's magnetic field with periods from few seconds to less than a year are caused by the electric currents in the Earth's ionized atmosphere. Since the geomagnetic field is a major controlling agent for the transfer of solar particle (plasma) energy to the lower terrestrial atmosphere, a large scale international effort is being undertaken to study solar terrestrial relationship under projects like STEP (Solar Terrestrial Energy Program) and IEEY (International Equatorial Electrojet Year).

At low latitudes, ±5 degrees around the magnetic equator, anomalous electric currents, called Equatorial Electrojets (EEJ), are present in the E region of the ionosphere giving rise to abnormally large daily variations in the H component of the geomagnetic field. Abnormally large daily variation range in H-component at the magnetic equator was first detected at Huancayo, Peru, in 1922. Later, this large range in Sq(H) was attributed to intense electric currents flowing in the equatorial E-region of the ionosphere. These currents were named EEJ by Chapman (1951) and soon its theoretical explanations came forward through the works of Baker & Martyn (1953) and Hirono & Kitamura (1956). A fair amount of knowledge on the EEJ is accumulated and reviewed by several authors, e.g. Forbes (1981), Raghavarao et al. (1989), Rastogi (1989) and Reddy (1989). Still much remains to be done for a complete understanding of the physical processes involved.

The magnetic equator and hence the EEJ pass across the Brazil in a way that there is considerable land on both the North and South of the EEJ. This is not found in any other single country. This geophysical fact makes the Brazilian participation in the IEEY very important. The scientific importance of EEJ studies in Brazil are reported by Kane & Trivedi (1980, 1982, 1985), Trivedi et al. (1989) and Barreto (1992). The Brazilian Committee of IEEY has written detailed description of the Brazilian IEEY Project, Abdu et al. (1991) and Abdu (1992). Extensive geomagnetic observations on profiles perpendicular to the EEJ in Brazil were planned since 1989. Hence the need arose to construct several low cost and low power fluxgate magnetometers. Here we present details of the magnetometer constructed in our laboratory for the IEEY program in Brazil.

FLUXGATE MAGNETOMETER

The use of fluxgate magnetometer is widespread, both at geomagnetic observatories and temporary magnetic stations, due to ease of its installation, and fairly good reliability. The electric analog output of a fluxgate magnetometer facilitates automatic digital data acquisition. The development of fluxgate magnetometer is due to Serson & Hannaford (1956), Trigg et al. (1971), Primdahl (1979) and Acuña (1974) among several others. One of the earliest paper on the subject by Aschenbrenner and Goubau published in 1936 was summarized and reported by Chapman & Bartels (1940). Our merit is in making the magnetometer as simple as possible, using commonly available electronic components and being able to make as many magnetometers as needed at a very reasonable cost.

The Fluxgate Principle

The principle of fluxgate magnetometer is illustrated by a schematic block diagram of one axis fluxgate magnetometer in Fig. 1. A fluxgate sensor consist of a high permeability ferromagnetic core on which primary and secondary coils are wound. An excitation current of frequency f is impressed on the primary coil which drives the sensor core into saturation twice every cycle of the excitation signal. Thus, the sensor core loses most of its permeability twice for each cycle of the excitation signal. The secondary winding wound around the same core picks up an alternating voltage signal at the second and higher even harmonics of the excitation frequency due to external magnetic field and the periodically varying core permeability. In general, efforts are made to isolate the primary excitation signal from the arriving secondary and higher even harmonic signals at the secondary winding. However, in practice some excitation signal leaks to the secondary winding. The amplitude and phase of each of the harmonics present at the secondary winding are proportional to the magnitude and polarity of the external magnetic field present along the axis of the secondary winding. However, the second harmonic signal represents best the varying amplitude and phase of the external magnetic field. Therefore, fluxgate magnetometers detect the amplitude of second harmonic by a synchronous phase detection technique to monitor the variations in the three orthogonal components of the Earth's magnetic field.

EXPERIMENTAL DETAILS

A typical fluxgate magnetometer consists of a sensor, amplifier, phase sensitive detector, integrator, oscillator and a calibrated biasing current source. A low distortion oscillator provides the excitation current for the three primary windings of orthogonally mounted fluxgate elements. The second harmonic signal from each secondary winding is amplified and fed into phase sensitive detector together with a reference signal that is twice the excitation frequency. The D.C. output from the phase detector is proportional to the field component directed along the axis of the corresponding fluxgate element. Each element is operated in near null field obtained by manually presetting the bias current to the secondary winding of the fluxgate element. An additional current proportional to the measured magnetic field is also directed into the secondary winding, providing negative feedback, which further ensures that the element is operated in near null field condition. The sensitivity of the fluxgate is determined by the feedback resistors value controlling the magnitude of the current in this feedback path.

Each of the components of a fluxgate magnetometer constructed at INPE for the IEEY geomagnetic program are described below.

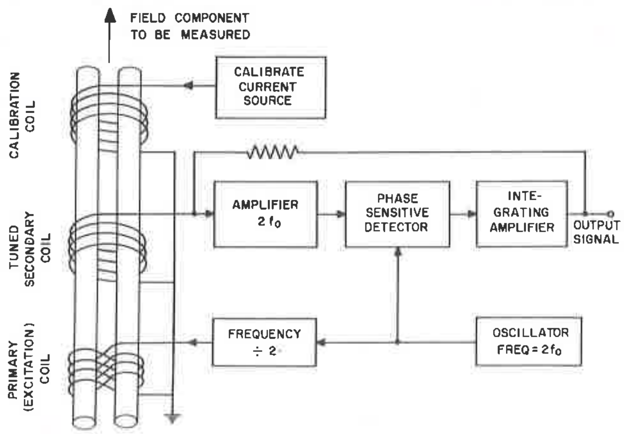

Figure 1 - Schematic block diagram of a fluxgate magnetometer.

Figura 1 - *Diagrama de bloco de magnetômetro fluxgate.*

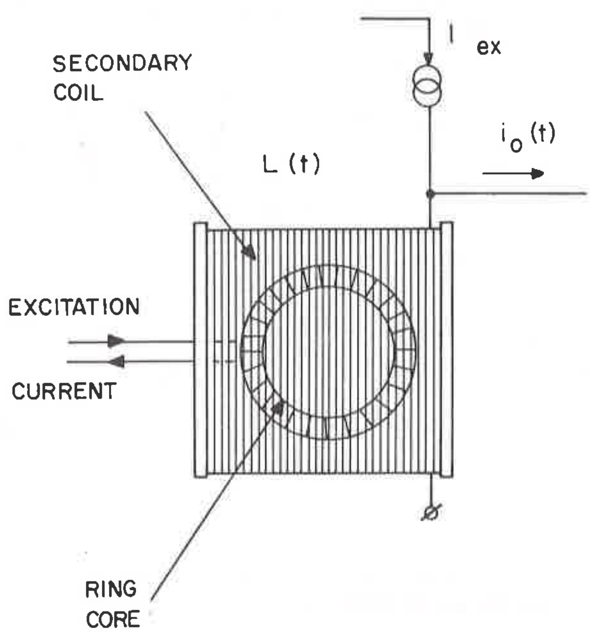

Figure 2 - Mechanical design of ring core sensor housing.

Figura 2 - *Desenho da caixa para acomodar o sensor de anel.*

Sensor

In our first magnetometer we have used linear bar sensors (LFG-A13) as shown in Fig. 1, manufactured by Kelvin Hughes, U. K.. Now we use ring core sensors. We buy the ring core nucleus (S625C31) from Infinetics, Inc., U. S. A. and build fluxgate sensors. The fluxgate ring core sensor is shown in Fig. 2. The drive winding is directly wound on the ring core about 100 turns of standard SWG 36 copper wire. The ring core then is fixed in a square case of teflon. The secondary winding of about 400 turns is wound on this square case. The primary winding is connected through a 1μf capacitor to an excitation oscillator of 9kHz. The output Io(t) of the secondary winding is fed to an amplifier. The secondary winding also receives the external reference current Iex for baseline compensation.

Oscillator and excitation

A crystal oscillator of appropriate frequency around 1MHz frequency is used so as to derive an excitation signal signal of 9kHz and the reference signal at twice the frequency of excitation signal as shown. The excitation signal is taken to a power amplifier (a pair of BD235 and BD236 transistors) before sending it on the primary winding . (Fig. 3).

Amplifier and phase detection

The most important part of the fluxgate magnetometer is its amplifier shown in Fig. 4. The first stage of this circuit is a current amplifier short circuiting the secondary coil as recommended by Primdahl et al. (1991). This procedure provides stability to the magnetometer and also reduces demands on the band pass filter circuit placed just before the synchronous phase detection stage. The second stage is for adjusting the phase of the incoming signal. One needs to correct the phase of the incoming signal from the secondary winding of the sensor as the phase of the excitation signal undergoes changes in the primary windings. The third stage is a buffer and low pass filter attenuating signal at excitation frequency. The fourth operational amplifier is a bandpass filter centered at 2f i.e. twice the excitation frequency. The fifth operational amplifier inverts the bandpass filtered signal for sending second harmonic signal at phase angles zero and 180 degrees to the synchronous phase detector 4053. Here the second harmonic signal is compared with the original reference signal from which the excitation signal is derived. The difference in phase between the two signals appear as a quasi direct current at the output of the integrated circuit 4053. This quasi direct current is subsequently integrated and fedback to the secondary coil through a right feedback resistor to keep the corresponding sensor element at near null field condition. An unknown referee has pointed out that the current amplifier used at the first stage of this circuit is unable to restrict the first harmonic component of the excitation signal entering the amplifier and the subsequent phase detection part of the circuit. Probably that could be a reason that we were forced to introduce a low pass filter circuit attenuating the signal near the excitation frequency just before the bandpass filter stage. However, we chose to use the current amplifier at the first instead of an amplifier tuned at the second harmonic signal for providing better temperature protection to our sensor and the magnetometer.

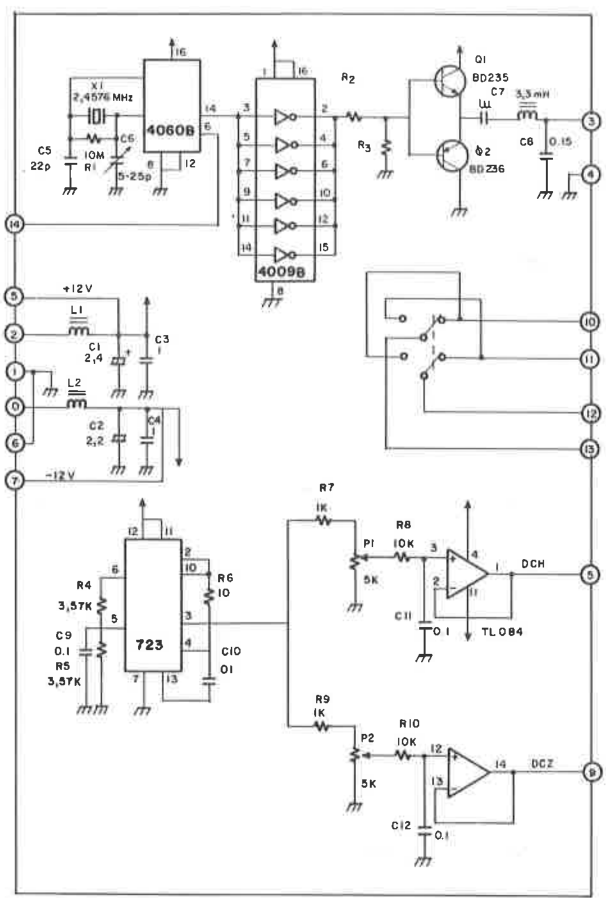

Figure 3 - Circuit diagram of oscillator and reference voltage

***Figura 3** - Diagrama do circuito de oscilador e voltagem de referência.*

Base line and reference voltage

The secondary coil of the sensor, besides the second harmonic signal, is superposed by a quasi D. C. field proportional to earth's magnetic field present along its axis. In order to keep the output analog signal proportional to the earth's magnetic field within the measurable limit of ±5 volts, one needs to supply base line reference voltage to compensate the quasi D. C. field of the earth magnetic field component present along the axis of the secondary bobbin. Fig. 3 shows the base line reference voltage used in this magnetometer. An IC CA723 provides the reference voltage in the circuit used here. The compensation current is sent to the respective secondary winding for components H and Z through a buffer amplifier as shown in the lower half of Fig. 3. The pin number 5 (for H component) and pin number 9 (for Z component) in Fig. 3 are connected to the point shown as E in Fig. 4 for providing compensation current to the respective secondary bobbins for H and Z components. When the North - South sensor is aligned in the magnetic meridian the output voltage from the East - West sensor (D component) is supposed to be zero. This fact waives the need of the current compensation circuit for the D component.

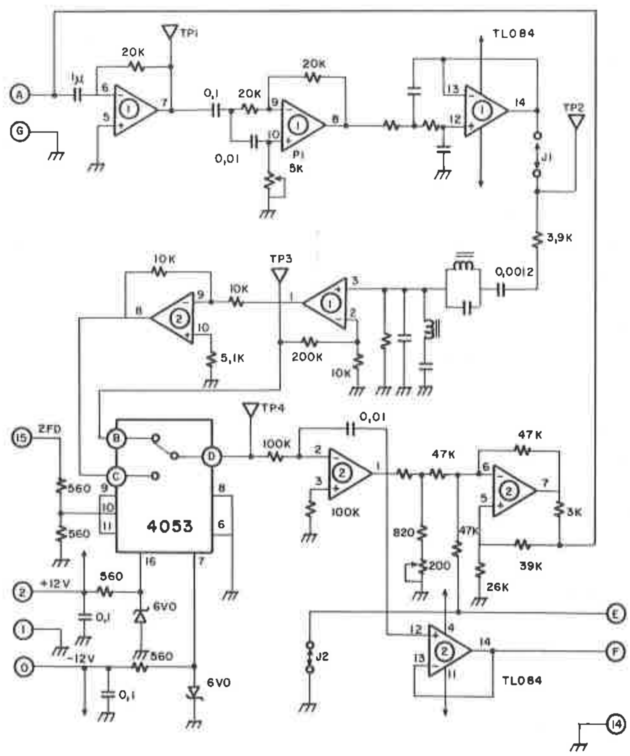

Figure 4 - Circuit diagram of amplifier and synchronous phase detection.

***Figura 4** - Diagrama do circuito do amplificador e detector síncrono de fase.*

Performance

The ring core sensors and the complete magnetometer electronics are housed in a PVC tube of about 20 cm in diameter and 35 cm in height. Normally, the magnetometer/PVC tube is buried at a depth of about a meter underneath the ground and connected by a multistrend shielded cable to a Data Logger and power supply placed in a building or a hut 30 to 50 meters away from the sensor. The multistrend cable takes ±15 volts D. C. to the magnetometer assembly and brings back three analog signals corresponding to geomagnetic field variations in its three orthogonal components. As shown in the diagrams certain baseline value is cancelled from the analog voltages using the reference voltage derived from dc integrated circuit CA723. Thus, only the variations in H, D and Z as bipolar analog signals are fed to the data logger. We do not monitor the entire field value of each of the three vector components since our datalogger uses an ADC of only 12 bits instead of the required 16 bits to monitor the entire value of the vector field. The process of data acquisition is controlled by Z80 CPU and the data are recorded on a one megabyte memory card (EPROM). Periodically, when the memory card is nearly full with the data we visit the station to read the data from EPROM memories.

The magnetometers constructed at INPE work satisfactorily for the purpose of monitoring geomagnetic daily variations in the H, D and Z components. Eight magnetometers were constructed to operate along a profile between Porto Velho (8.46° S, 63.54° W) at dip angle 6.4 degrees and Cuiabá (15.57° S, 56.12° W) at dip angle -11.0. The locations of the eight magnetic stations on both North and South of the magnetic equator are shown in Fig. 5. Several magnetometers were operated simultaneously for testing at INPE's facilities in Cachoeira Paulista (22.7° S, 45.0° W). The recorded daily variation from the seven magnetometers on July 26, 1992, is shown in Fig. 6. The simultaneous record from all seven magnetometers look almost identical confirming exactly the same performance of the magnetometers. In Fig. 7 an example of smoothed magnetograms recorded at various field stations in the EEJ region confirm successful construction and operation of the magnetometers. The station Pimenta Bueno (11.6° S, 61.2° W) is closest to the center of the EEJ where, as expected, the range of daily variation in H component of the geomagnetic field is found largest. During a magnetic storm on 5th. June 1991, the magnetic record obtained at Pimenta Bueno was compared with the record obtained at a nearby magnetic observatory of Huancayo, Peru, also very close to the center of the EEJ. The geomagnetic observations at both the stations are identical as shown in Fig. 8.

SUMMARY AND RECOMMENDATIONS

A dozen of three component ring core fluxgate magnetometers were constructed at INPE. They show a precision better than 0.5 nT. We found very difficult to operate several magnetic stations simultaneously and obtain reliable results. The range of Sq.(H) variations may have different amplitudes depending on the distance of the station from the center of the EEJ currents but the geometry of the variations seen at all the stations should be identical. We took some time to find out that we need to use a better temperature stabilized precision voltage reference integrated circuit than CA723 or just 723. The temperature coefficient of CA723 is 0.003%/centigrade. We replaced 723 by LM399A which has a temperature coefficient of 0.00005% per degree centigrade. Also we had to replace few multiturn carbon potentiometers by wire wound potentiometers. If we have to start this project again we would completely eliminate compensation circuits either using CA723 or LM399A. We would rather operate magnetometers at a lower sensitivity such that 1 volt of output would correspond to 12000 nT and use a 18 bits Analog to Digital Converter in the Data Logger.

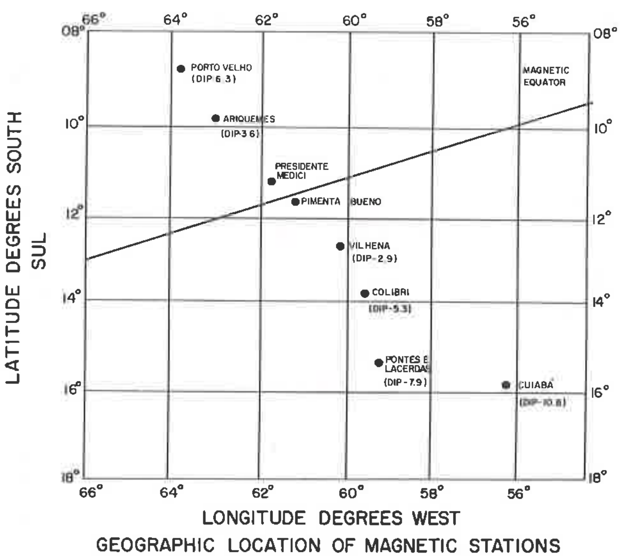

Figure 5 - Geographical locations of magnetic stations.

Figura 5 - *Localização geográfica das estações magnéticas.*

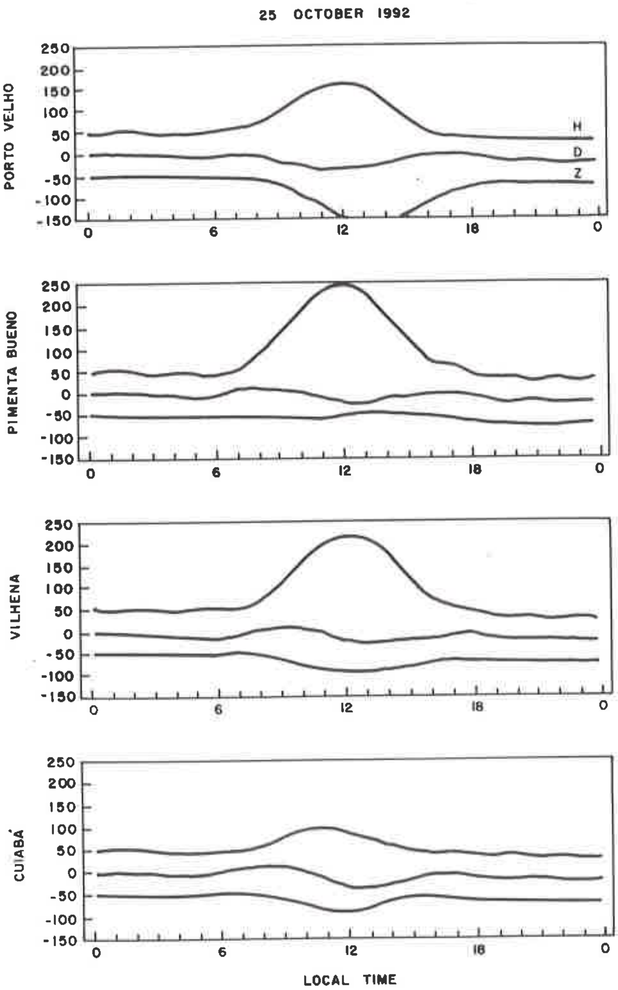

Figure 6 - Simultaneous record of seven magnetometers operated at Cachoeira Paulista on 26 July 1992.

***Figura 6** - Registro simultâneo de sete magnetômetros operados em Cachoeira Paulista no dia 26 de julho de 1992.*

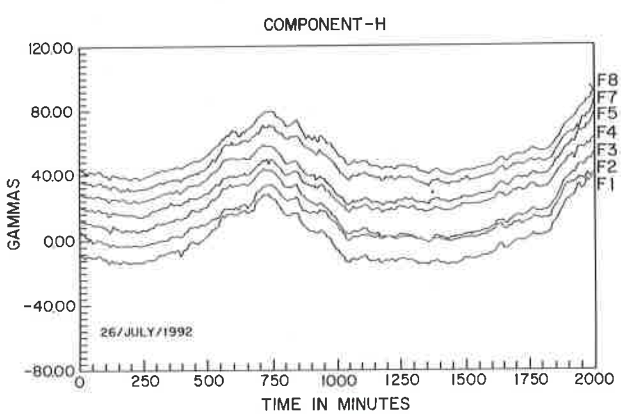

Figure 7 - Daily variation in H, D and Z on 25 oct. 1992 at Porto Velho, Pimenta Bueno, Vilhena and Cuiabá.

***Figura 7** - Variação diurna H, D e Z no dia 25 de outubro de 1992 em Porto Velho, Pimenta Bueno, Vilhena e Cuiabá.*

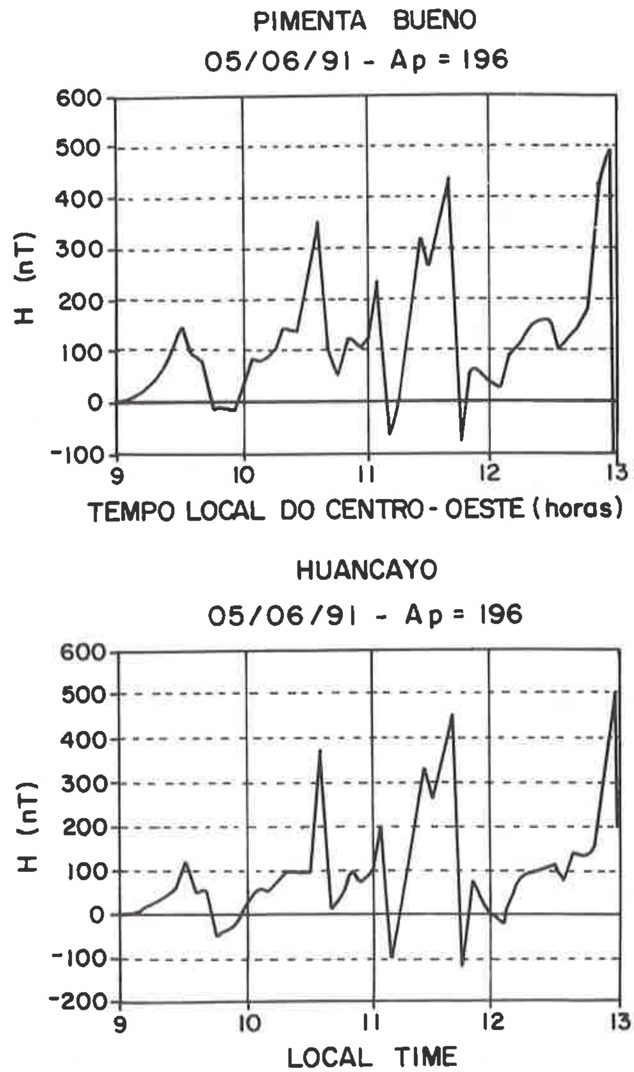

Figure 8 - Storm time variation in H during 09:00-13:00 hours L.T. on 5 June 1991 at Pimenta Bueno and Huancayo.

***Figura 8** - Variação em H durante uma tempestade, 09:00 a 13:00 horas locais no dia 5 de junho de 1991 em Pimenta Bueno e Huancayo.*

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