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18. *Improvement of Sea-going Proton Magnetometer.*

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Summary

An automatic recording (digital and analogue) all-transistorized sea-going proton magnetometer has been developed. A crystal-controlled programmer operates the instrument automatically every minute, the frequency of the proton precession signal being multiplied by twenty and counted for 1.1743 sec giving a reading in gammas. A comparison test with a Varian Meter was conducted off San Francisco aboard s.s. Pioneer of the United States Coast and Geodetic Survey. The results were found to be satisfactory.

1. First Improvements

Proton precession magnetometers have been developed at the Earthquake Research Institute.[1),2),3)] In the earlier sea-going instruments, the precession signals were mixed with standard frequency signals and the resultant beat signals were recorded by a pen-oscillograph on each measurement. This subsequently entailed much work in reading the re-

1) Research Group for Proton Magnetometers, *Bull. Earthq. Res. Inst.*, **36** (1958), 433.

2) Research Group for Proton Magnetometers, *Bull. Earthq. Res. Inst.*, **38** (1960), 125.

3) T. RIKITAKE and I. TANAOKA, *Bull. Earthq. Res. Inst.*, **38** (1960), 317.

cords and computing the field values.

To avoid this, direct counting of the proton precession cycles has been attempted. In the first step, a vacuum-tube amplifier for a differential proton magnetometer[3] was utilized in connection with a motor driven cam programmer which operates the machine every two minutes. The frequency of precession signals was multiplied by ten through a frequency multiplier (Yokogawa, FC-11) and then was counted by a digital frequency counter (Oki, WF-312) for one second. The outputs were printed by an electric typewriter with the aid of a digital data controller (Oki, WX-302). A *D-A* converter manufactured by Oki Electric Industry Co. was installed in the counter chassis and the last three decimals of the output signals were recorded by a TOA EPR-2T electronic polyrecorder.

The block diagram of the system is shown in Fig. 1. Since the

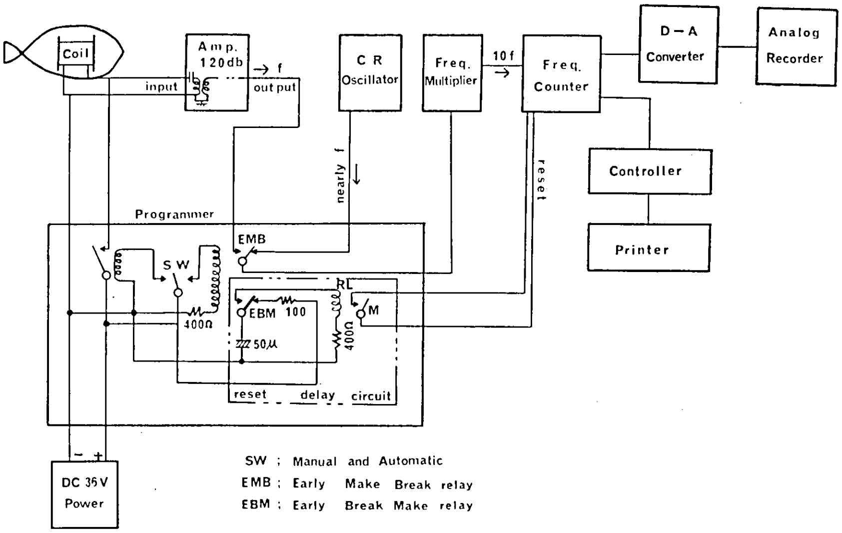

Fig. 1. Block diagram of the sea-going proton magnetometer (first improvements).

frequency multiplier starts working properly only from about ten seconds after receiving the input signal, while the proton signals last only about two seconds, a continuous signal of about 2 kc/s has to be fed to the multiplier from a *C-R* audio oscillator. This continuous signal serves to keep the free-running frequency of the multiplier circuit near by the proton precession cycle, so that the multiplier works instantaneously when an "early-make-break" relay switches over the input signal from the continuous signal to the proton signal. This device proved to work well, although somewhat complicated the programmer. The programmer also contained a delay circuit for the counter so that the counter started to count the signal frequency after the transient shocks had decayed. The delay time was about 150 msec. Tuning of the amplifier was done by two sets of twin-*T* circuit, one to cut the 50 cycle noises and the other tuned to the precession cycles.[3] The latter tuning-frequency was adjusted manually as the signal frequency changed so that the tuning frequency was kept always within about 20 c/s range of the signal frequency.

The above system was used during the cruises of JEDS-VI and JEDS-VII (Japanese Expedition of Deep Seas) in 1963 and worked fairly well.[4]

2. Second Improvements

Since the direct counting system described above was proved practicable, it was felt in the second stage that improvements should be made on the amplifier and programmer apparatus. Thus, an entirely new amplifier and programmer system was designed by one of the authors (Y.T.). The block-diagram of the system is shown in Figs. 2 and 3.

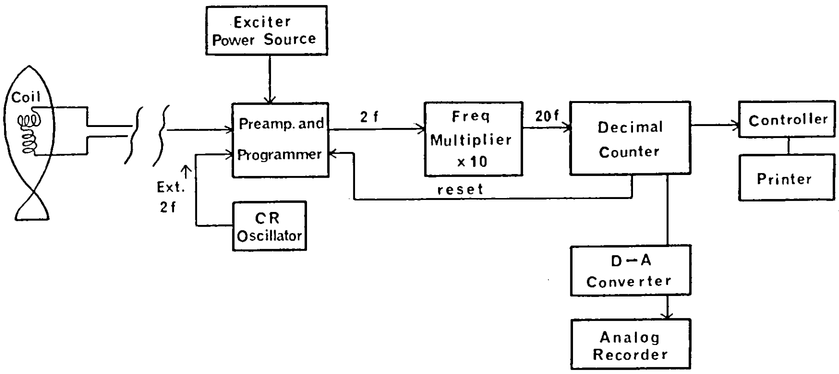

Fig. 2. Block diagram of the sea-going proton magnetometer (second improvements).

The signal (*f*) is fed to the amplifier through an *L-C* tuner composed of the sensing coil and a decade capacitor. The amplifier is a four-stage transistorized type having 100–120 db amplification. Tuning of the am-

4) S. UYEDA, T. SATO, M. YASUI, T. YABU, T. WATANABE, K. KAWADA and S. HAGIWARA, to be published in *Bull. Earthq. Res. Inst.*, (1964).

plifier is made by an array of capacitors. The measurable field intensity range is from 30000 γ to 58000 γ. The band width is about 500 γ. The output signal (f) is multiplied either by two or four through doublers. Usually a $2f$ signal is used. Doubled signals are sliced by a slicer

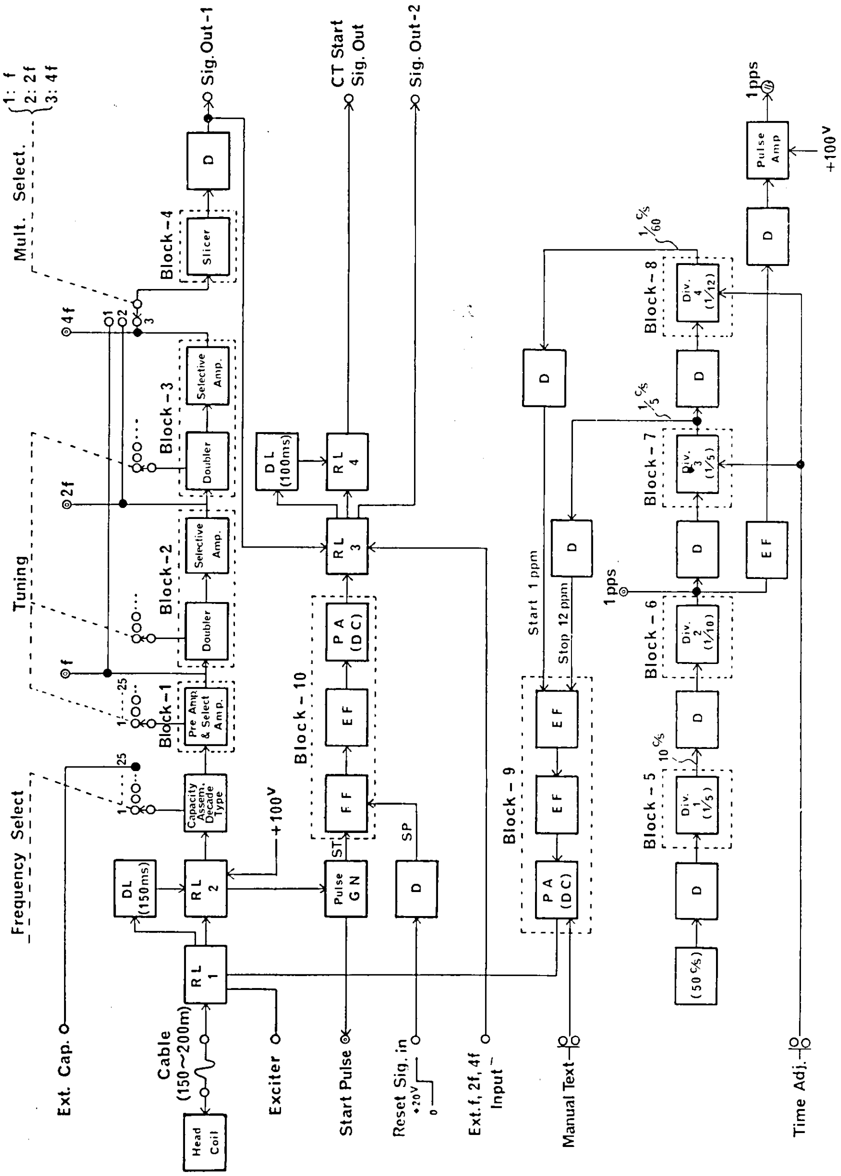

Fig. 3. Block diagram of the amplifier and programmer apparatus.

having a slicing level of 0.1–0.2 V. and fed to the counter through a Yokogawa Fe-11 frequency multiplier ($\times$ 10). A continuous external signal with frequency nearly $2f$ (or $4f$) is fed to the amplifier as in the previous case.

The programmer is controlled by a 50 c/s crystal oscillator and the standard frequency of 50 c/s is divided by a series of frequency dividers to give time signals needed for the operation. The time-chart for the operation is shown in Fig. 4.

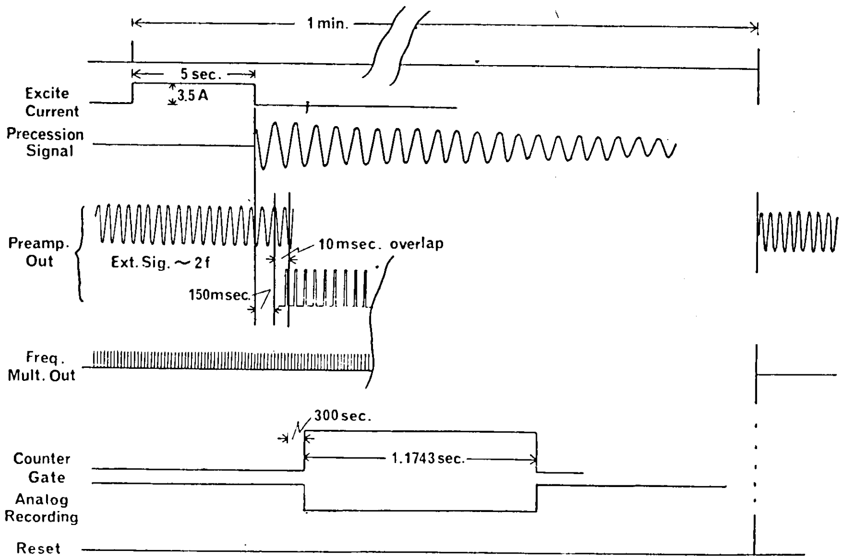

Fig. 4. Time-chart for the operation of the sea-going proton magnetometer.

Two sensing coils directed perpendicularly to each other are put in a fish made of transparent plastics. The fish is towed behind the ship as usually by a 200 m coaxial cable reinforced by a non-magnetic metal coating net. The counter gate opens for 1.1743 sec giving a reading in gammas.

3. Comparison with a Varian Instrument Under a U. S.-Japan Cooperation Research Program

A comparison program of sea-going geophysical instruments between the United States Coast and Geodetic Survey and the University of Tokyo was carried out in October, 1963 under the US-Japan Cooperation Research Program. The main objective of the program was the comparison of the LaCoste and Romberg Air-Sea gravitymeter and the Tokyo surface-ship gravitymeter against a fixed standard by simultaneous use of the two instruments on the same ship over an established gravity range. It was considered advantageous to make use of this opportunity for making a comparison of ship-borne magnetometers on the same ship at the same time. Since both the magnetometers to be compared are proton precession type of which the working principle depends upon a well established universal constant of protons, the comparison was not as critical as in the case of gravitymeters still in the testing stage. In this section, the result of the comparison of magnetometers will be reported briefly. The comparison was made on the 16th Oct., 1963 on the United States Coast and Geodetic Survey Ship Pioneer in the Oceanographic Equipment Evaluation Range set up by the Survey off San Francisco.[5] The Japanese instruments were shipped from Tokyo by air to San Francisco for loading on the Pioneer at the port of Oakland. Fishes of both U. S. and Japanese instruments were towed simultaneously and measurements made every minute from 09 h 02 m to 16 h 10 m on the 16th of October, 1963. It was intended that measurements of the Japanese instrument be made every full minute and that of the U. S. instrument on the 30 seconds of every minute in order to avoid possible interferences. This program, however, was not followed strictly because some trouble occurred with the counter of the Japanese instrument and manual testing often disturbed the measurement time schedule.

The Varian instrument used printed out the period (T) of the pression signal, while the Japanese instrument printed out the gamma value (F), so that for comparison the U. S. results were converted to gamma values by the equation

$$F=\frac{1}{23.4865}T$$

The results are tabulated in Table 1 and illustrated in Fig. 5. The U. S. data were made available to us through Dr. H. Orlin of the U.S. Coast and Geodetic Survey. As was expected, the agreement between the two instruments was reasonably good but not quite perfect. There were descrepancies amounting to several gammas, but these did not seem to be systematic. The cause of the discrepancies may have been due partly to the time difference between the measurements of the two instruments and partly to the oscillation of the fish

5) H. ORLIN, R. B. JONES, K. F. FANNING and S. K. GRAOUTTE, "Sea Gravity Phase", *Oceanographic Equipment Evaluation Range*, July 1962., *U.S. Coast and Geodetic Survey.*

Table 1. Results of simultaneous measurement of the geomagnetic total force by the U. S. and Japanese instruments, Oct. 16, 1963.

Time	Japanese data (gamma)	U.S. data (gamma)	Time	Japanese data (gamma)	U.S. data (gamma)
09 h 00 m	51.379		09 h 50 m		
01	51.377		51	51.390	
02		51.378	52		51.395
03	51.379	51.378	53		
04	51.370	51.378	54		
05	51.375	51.376	55		51.395
06	51.375	51.376	56		51.394
07	51.377	51.375	57		
08	51.370	51.375	58		
09	51.286	51.370	59		
10		51.370	10 00		51.394
11	51.370	51.369	01		51.395
12	51.371	51.374	02		51.394
13	51.369	51.374	03		51.394
14		51.374	04		51.393
15	51.373	51.374	05		51.396
16	51.371	51.373	06	51.394	51.396
17	51.371	51.374	07	51.394	51.397
18	51.373	51.373	08	51.396	51.400
19	51.363	51.374	09		51.401
20		51.376	10		51.401
21	51.370	51.374	11	51.400	51.402
22	51.375	51.376	12	51.401	51.404
23	51.370	51.377	13		51.409
24	51.371	51.376	14		51.407
25	51.371	51.376	15		51.410
26	51.375	51.374	16		51.410
27	51.375	51.378	17		51.412
28	51.373	51.377	18		51.413
29	51.375	51.376	19		51.414
30	51.378	51.377	20		51.414
31	51.376	51.378	21	51.412	51.415
32			22	51.412	51.418
33	51.376	51.433	23		51.416
34	51.379	51.382	24	51.414	51.415
35	51.379	51.383	25	51.414	51.415
36	51.380	51.383	26		51.416
37	51.381	51.384	27		51.415
38	51.382	51.386	28		51.416
39	51.384	51.387	29		51.418
40		51.386	30	51.415	51.418
41	51.387	51.389	31		51.418
42			32		51.416
43	51.387	51.394	33		51.416
44		51.393	34		51.418
45	51.391	51.392	35		51.419
46	51.390	51.394	36	51.416	51.419
47	51.394	51.394	37		51.420
48	51.390		38		51.321
49	51.383		39		51.420

(to be continued)

(continued)

Time	Japanese data (gamma)	U.S. data (gamma)	Time	Japanese data (gamma)	U.S. data (gamma)
10 h 40 m		51.422	11 h 30 m		51.449
41		51.424	31	51.444	51.451
42	51.418	51.422	32	51.444	51.452
43		51.420	33	51.443	51.450
44	51.418	51.421	34		51.450
45		51.420	35		51.452
46	51.419	51.419	36		51.452
47	51.415	51.419	37		51.454
48	51.415	51.420	38	51.450	51.454
49	51.416	51.418	39	51.446	51.450
50	51.418	51.421	40	51.447	51.451
51	51.418	51.420	41	51.446	51.454
52	51.418	51.421	42		51.459
53	51.420	51.422	43	51.453	51.457
54	51.419	51.424	44	51.453	51.458
55	51.422	51.424	45	51.457	51.459
56	51.422	51.427	46	51.457	51.459
57	51.422	51.425	47	51.454	51.458
58	51.423	51.427	48	51.454	51.457
59	51.426	51.430	49		51.459
11 00	51.425	51.431	50		51.457
01		51.431	51	51.455	51.456
02		51.430	52	51.454	51.455
03	51.427	51.434	53	51.452	51.454
04	51.434	51.432	54	51.447	51.454
05	51.431	51.434	55	51.453	51.454
06	51.434	51.434	56		51.454
07	51.433	51.439	57	51.449	51.452
08	51.435	51.436	58	51.449	51.454
09	51.433	51.440	59	51.447	51.451
10	51.438	51.439	12 00	51.448	51.452
11		51.440	01		51.450
12	51.436	51.440	02		51.450
13	51.439	51.440	03		51.448
14	51.437	51.441	04	51.447	51.447
15	51.438	51.439	05	51.485	51.449
16	51.436	51.438	06		51.454
17		51.438	07		51.454
18	51.436	51.446	08		51.446
19	51.432	51.440	09		51.446
20	51.434	51.439	10	51.446	51.445
21		51.440	11	51.444	51.446
22	51.436	51.443	12		51.439
23	51.444	51.445	13		51.441
24		51.445	14		51.439
25	51.440	51.445	15		51.439
26		51.443	16	51.444	51.437
27		51.445	17	51.435	51.433
28		51.447	18	51.429	51.431
29	51.445	51.448	19	51.430	51.432

(to be continued)

(continued)

Time	Japanese data (gamma)	U.S. data (gamma)	Time	Japanese data (gamma)	U.S. data (gamma)
12 h 20 m	51.425	51.431	13 h 10 m	51.413	51.411
21		51.428	11	51.409	51.410
22		51.427	12	51.407	51.406
23		51.425	13		51.407
24	51.421	51.423	14		51.405
25	51.421	51.421	15		51.404
26	51.418	51.419	16		51.404
27	51.416	51.418	17		51.405
28		51.415	18		51.404
29	51.411	51.415	19		51.403
30	51.414	51.416	20		51.398
31	51.411	51.413	21		51.401
32		51.414	22		51.398
33		51.412	23		51.397
34	51.409	51.412	24		51.400
35		51.414	25		51.398
36	51.414	51.413	26		51.397
37	51.410	51.414	27		51.397
38	51.412	51.414	28		51.393
39	51.418	51.414	29		51.391
40	51.410	51.416	30		51.393
41	51.415	51.416	31		51.391
42	51.416	51.415	32		51.391
43	51.414	51.416	33		51.392
44	51.415	51.418	34		51.389
45	51.414	51.419	35		51.388
46	51.415	51.416	36		51.391
47	51.417	51.421	37		51.388
48	51.418	51.419	38		51.389
49	51.420	51.419	39		51.388
50		51.423	40		51.388
51		51.423	41		51.389
52		51.425	42		51.391
53		51.427	43		51.392
54		51.427	44		51.387
55		51.424	45		51.388
56		51.425	46		51.391
57		51.425	47		51.387
58		51.427	48		51.386
59		51.424	49		51.389
13 00		51.422	50		51.387
01		51.422	51		51.385
02		51.421	52		51.385
03		51.421	53		51.387
04	51.420	51.418	54		51.391
05	51.418	51.418	55		51.386
06	51.418	51.415	56		51.387
07	51.415	51.414	57		51.388
08	51.415	51.412	58		51.386
09	51.412	51.410	59		51.388

(to be continued)

(continued)

Time	Japanese data (gamma)	U.S. data (gamma)	Time	Japanese data (gamma)	U.S. data (gamma)
14 h 00 m	51.384	51.385	14 h 50 m	51.389	51.393
01	51.384	51.388	51	51.387	51.394
02	51.384	51.389	52	51.388	51.396
03		51.388	53	51.393	51.391
04	51.385	51.387	54	51.388	51.388
05	51.386	51.388	55	51.389	51.392
06		51.388	56	51.389	51.387
07	51.369	51.388	57	51.387	51.387
08	51.389	51.388	58	51.387	51.388
09	51.387	51.386	59		51.388
10	51.385	51.387	15 00	51.392	51.393
11	51.376	51.388	01	51.387	51.396
12	51.390	51.388	02		51.391
13	51.388	51.386	03	51.392	51.396
14		51.389	04		51.394
15	51.388	51.387	05	51.392	51.395
16	51.388	51.388	06		51.995
17	51.388	51.391	07	51.395	51.396
18		51.388	08		51.396
19	51.386	51.391	09	51.392	51.396
20	51.367	51.388	10	51.396	51.397
21	51.389	51.391	11	51.396	51.394
22		51.392	12	51.393	51.396
23		51.391	13	51.394	51.395
24		51.393	14	51.393	51.394
25	51.392	51.395	15	51.388	51.394
26	51.391	51.394	16		51.394
27	51.393	51.395	17	51.390	51.395
28	51.394	51.397	18	51.394	51.396
29	51.398	51.400	19		51.394
30	51.395	51.396	20	51.393	51.394
31	51.396	51.398	21	51.394	51.398
32	51.399	51.402	22		51.402
33		51.406	23	51.401	51.400
34		51.407	24	51.405	51.400
35	51.405	51.403	25	51.375	51.404
36	51.400	51.401	26	51.393	51.403
37	51.399	51.403	27		51.400
38	51.377	51.403	28		51.398
39		51.400	29		51.397
40	51.399	51.395	30	51.396	51.398
41	51.397	51.394	31		51.398
42	51.392	51.393	32		51.398
43	51.391	51.396	33		51.401
44	51.392	51.392	34		51.398
45	51.394	51.393	35		51.395
46	51.394	51.394	36		51.393
47	51.394	51.391	37	51.392	51.398
48	51.388	51.393	38	51.388	51.396
49	51.390	51.393	39	51.391	51.398

(to be continued)

(continued)

Time	Japanese data (gamma)	U.S. data (gamma)
15 h 40 m	51.394	51.397
41		51.396
42	51.392	51.394
43	51.391	51.396
44		51.395
45		51.395
46	51.402	51.393
47	51.394	51.394
48	51.393	51.398
49		51.398
50		51.400
51		51.400
52		51.403
53		51.403
54		51.401
55		51.405
56		51.405
57		51.406
58		51.412
59		51.412
16 00		51.411
01		51.413
02		51.410
03		51.411
04		51.405
05		51.405
06		51.406
07		51.404
08		51.401
09		51.395
10	51.394	51.394

in the water. An oscillation of one cycle per second would cause a noise in the record amounting to 23 gammas. It was observed that the Japanese fish came up to the surface and kept jumping when the ship's speed exceeded 14 knots. Taking these factors into consideration, it may be said that both instruments gave practically correct values.

Acknowledgment

Acknowledgment is made of the partial financial support of this investigation through a grant from the Japan Society for Promotion of Science (JSPS) as part of the U.S.-Japan Cooperative Science Program. The authors would like to thank Prof. C. Tsuboi and Prof. T. Rikitake for their supervision of the work and the staff of the Japan Society

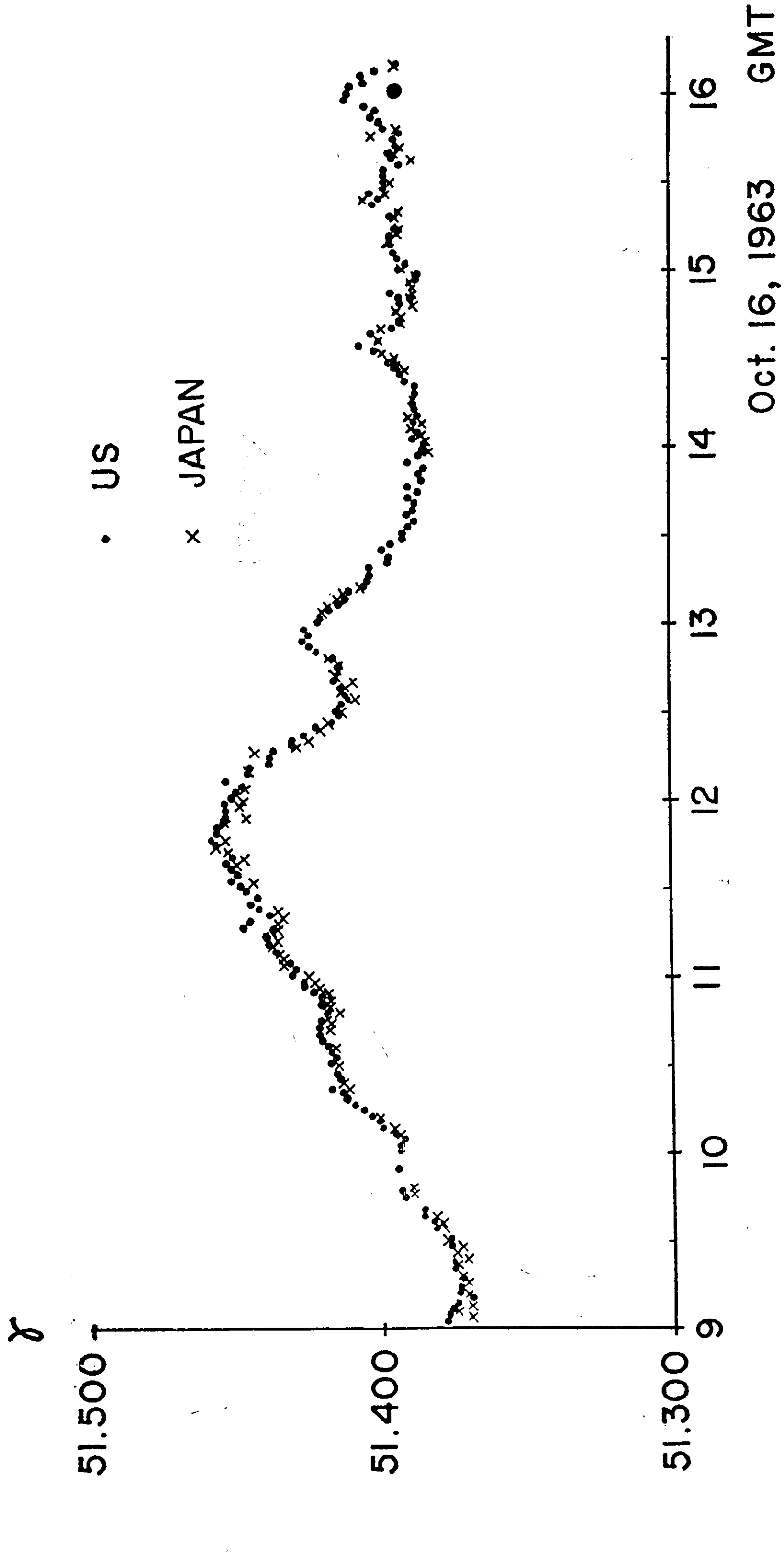

Fig. 5. Results of the simultaneous total force measurement by the U.S. and Japanese instruments.

for Promotion of Science for their help. For the operation on board s/s Pioneer, we enjoyed the kind offices of Admiral H. A. Karo and the cooperation of Captain E. B. Brown, Dr. H. Orlin and all the crew members to whom the authors are most grateful.

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18. 船上用プロトン磁力計の改良

地震研究所 上 田 誠 也
海洋研究所 友 田 好 文
地震研究所 藪 武 夫
水 路 部 歌 代 慎 吉

従来，ペンオツシログラフによつて，標準周波数信号との唸り信号を記録し，一々，地磁気全磁力を計算してきたプロトン磁力計を，周波数直読方式，自動運転方式に改良した．信号は，その周波数を 20 倍され，1.1743 秒間だけ計数されることによつて，γ の値そのものとなつて，毎分一回，自動的に印字記録され，同時に，アナログ記録計によつても記録される．

すでに米国において，商品化しており，実用されている Varian 会社製の同様の磁力計との比較測定は，日米科学協力計画の一環として，1963 年秋，合衆国沿岸測地部の観測船 Pioneer 号上で行なわれた．実施場所は，サンフランシスコ沖の海洋測器試験海域であつて，比較測定の結果は，良好であつた．但し，時に数 γ の差が両装置からの結果にみられた．