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by

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THE LASER RANGING OF ETALON SATELLITES

Performed by the Shanghai Astronomical Observatory
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ABSTRACT

This paper presents a summary of the laser ranging of 2 geodynamics satellites <<Etalon>> launched by the USSR, observed by the Shanghai Astronomical Observatory. From April to December of 1990, data of laser ranging of totally 73 passes were obtained, among which a maximum of 4,256 ranging data have been recorded in each pass, and the ranging distances sometimes exceeded 20,000 km.

1. Introduction

In recent years, the precision in man-made satellite laser ranging (simply called as SLR) has been continuously being improved. Its applications are reaching wider and farther everyday. Prior to the early part of the 70's, because the launched laser satellites, such as the Explorer series, had irregular shapes the uncertainty in the satellite centers required corrections, thus demanding improvements in ranging accuracy and at the end gradually they were discarded from the tracking schedule. After the synchronized observation of MERIT, the chief objective of

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* Numbers in margins indicate foreign pagination. Commas in numbers indicate decimals.

[1] Shanghai Astronomical Observatory, Academia Sinica, Shanghai 200030. Received on December 19, 1991.

the global laser network tracking only kept 3 spherically shaped satellites: Lageos, Ajisai and Starlette. Due to recent developments in the application potential of the SLR technology, a set of new laser satellites are now under study.

Etalon-1 and Elaton-2 satellites are 2 early models[1] of the laser global geodynamics satellite series, developed by the USSR and launched into orbits on January 10 and May 31 of 1989, respectively. Their outer appearances are totally identical, namely spherical passive satellites of diameter 1.293 m, weight 1,415 kg, the ratio of area to weight 0.00094 m^2/kg, and equipped with more than 2,000 sets of laser reflectors on their surfaces. Both satellites had almost the same identical circular orbits, eccentricity merely of 0.0007, the inclination angles with respect to the orbits were 64°8', semi-major axes of about 25,487 km, periods of 11 hours 15 min, altitudes about 19,120 km and presenting themselves as stable long-distance laser ranging targets.

Due to their high altitudes, they possess the following characteristics:

1. They are insensitive to the geogravitational field and thus better than Lageos in determining the parameters of the earth revolution, especially for UT1;

2. A satellite at a high orbit allows increasing the interdistances between observation posts. Thus it has the advantage of distributing them over the baseline of different tectonic plates;

3. A long duration of satellite-ranging with a period of 12 hrs has the advantage of improving precision of ranging

in the 2nd order and even in the 3rd order "Dixie Coefficients";

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4. Satellites at an altitude of 20,000 km receive effects from the lunar perturbations at 15 - 20 times more than that at altitudes of 2,000 - 6,000 km, and thus this is an advantage in measuring the mass variation rate of the geo-lunar system.

Due to the important application values of Etalon satellites, they received immediate attention as soon as they were launched, becoming one of the important tracking objects for the entire global network. In September of 1990, specialists cooperating in SLR of the international earth rotation services (IERS) organized a global synchronized observation in the span of 3 months. The purpose was to collect sufficient concentrated observational data to make a precise determination of the orbits of Etalon satellites and at the same time to evaluate geodynamics of the satellites toward the earth and its contribution to the measurement of movements of the global tectonic plates.

The laser ranging station of the Shanghai Astronomical Observatory (International series number 7837) took part in this synchronized observation, obtained a series of observational results, and effectively extended the distances of this ranging system to 20,000 km.

2. Improving the Ranging system and its real-time prediction

The functional parameters of the satellite laser ranging system of the Shanghai Astronomical Observatory have already been introduced elsewhere in detail[2]. The diameter of the telescopic mirror of the receptor is 60 mm, it is placed on a horizontal frame and the precision of the orienting angle is up to 10 angular seconds. As the laser, Nd:YAG device of the principal passive switching model was used, and its single pulse energy was about 50 mJ (0.532 μ), the pulse-width was 180 psec and the repetition rate of 1 - 2 Hz. The timely resolution power of the interval-setting timer was 20 psec (HP5370B). One IBM/286 microcomputer was used to control the entire tracking and ranging system, and only one single observing personnel was needed for the operation of the entire observation process.

In order to adjust to the observation of Etalon Satellites, we worked out a little improvement in responsiveness:

1. Because the distance of Etalon satellites from the earth were more than 20,000 km, it exceeded the original design range (8,500 km) of the ranging system. Consequently, we revised the control-delay value of the distance-gate of the soft- and hard-ware. From 80 ms it was raised to 150 ms, and the installation of this value can clearly guarantee observations above 20° from the horizon, and also insure raising the laser repetition rate up to 5 times/sec.

2. To compare with Lageos satellite, the strengths of the echo waves from Etalon were weakened by 4 - 10 times, the ratio with respect to noise has also gone down, and in order to allow effective recognition of the echo waves even in the noise we designed a command into our tracking software to display the real-time ranging residual on the monitor. The ranging residual $\Delta\rho$ can be obtained by subtracting the forecast value ρ_o from the observed value ρ_c, by making the computer process it in real-time and then displaying it on its monitor. One screen of monitored images could run

continuously through the display of 99 values of ranging residuals. The residual values of the satellite echo waves were approximately arranged on a straight line in an orderly manner on the monitor, while the noises were distributed along with them. The observer could determine whether the target had been hit or not directly from the images on the screen, by micro-managing the tracking direction of the telescope and adjusting the distance gate. In this way the bull-eye rate was greatly improved and it helped realize the searching of the targets from the earth-based images.

3. The satellite forecasting was made with the long-duration time-tables supplied by the U. S. Texas University Space Research Center (CSR). Such time-tables give the satellite positions and velocity vector-values of daily zero-points. At the same time it also provides long forecast values of the geo-revolutional parameters at Texas. This paper made 2 revisions to the original satellite forecast software: (1) it adopted the most recent values x_p and y_p of the extreme displacements from the IERS Bulletin and at the same time for UTI-UTC, the corresponding corrections DIF = IERSUT - TEXUT; (2) Based on the forecast reports, the residual $\Delta\rho_{(o-c)}$, of the ranging values was computed every time when the satellite was making a pass, and then by use of the linear approximation, the deviation in distance (a) and in time (b) of the forecast orbit was obtained to be :

$$\Delta\rho_{(o-c)} = a + b\dot{\rho},$$

(where $\dot{\rho}$ is the partial differentiation of the inclined distance ρ with respect to time), and after they had been corrected, forecasts were made for the next few rounds. By going through the above revisions the position forecast and distance forecast could all be improved, especially the error in the position forecast which could be limited to within 30 m. It was good for the accurate tracking of the satellites, as well as the predicted values of the compressed distance gate, and thus the success rate of observations was improved.

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The observable arc-length of each passing of Etalon satellite was rather long and the arc-stage above 20° from the horizon could reach 3 - 5 hours. Thus during the tracking period, one could insert the observations made on other satellites. The turnover of the ranging system from the tracking object needs only about 1 min, and thus it turned out to be quick and convenient.

3. The results of observations

On April 25, 1990, the Shanghai Station first received a laser echo from Etalon-1, but the next day it already received an echo from Etalon-2. Afterwards, these 2 satellites were immediately listed in the regular observation schedule of the Shanghai Station. Toward the end of 1990, altogether it received 38 rounds of Etalon-1 data and 22,222 observation points; 35 rounds of Etalon-2 data and 10,402 observation points. Among them the largest points obtained from Etalon-1 were 4,138 points in one single around, while it was 4,256 points in one around of Etalon-2. The observed results were all sent to the global laser data collection center: The U. S. National Aerospace Agency "Getate" (Kennedy) Space Flight Center (NASA/GSFC).

Table 1 Summary of Global Synchronized Tracking of Etalon Satellites (September 1 - December 1, 1990)

观测站 (Station) 1	Etalon-1		Etalon-2	
	2 圈 数 (Passes)	3 标准点数目 (NP Obs)	2 圈 数 (Passes)	3 标准点数目 (NP Obs)
1181 波茨坦(德)	4	82	6	142
1873 Simeiz (苏)	9	306	7	265
1893 Katsiveli (苏)	8	391	17	853
1884 里加(苏)	1	3	3	61
1953 圣地亚哥(古巴)	1	18	1	14
7080 麦克唐纳台(美)	23	1444	21	1100
7105 戈达德飞行中心(美 NASA 站)	4	197	12	563
7109 Quincy (美, NASA 站)	3	115	3	175
7110 Monument Peak (美, NASA 站)	20	1214	26	1655
7210 Haleakala (美)	5	245	4	177
7236 武汉(中国)	4	228	4	187
7308 东京(日)	27	320	16	152
7834 Wettzell (德)	4	146	—	—
7835 Grasse (法)	11	564	16	869
7837 上海(中国)	18	854	17	690
7839 Graz (奥)	7	166	1	25
7840 格林尼治台(英)	27	447	19	268
7843 Orroral (澳)	15	777	10	649
总计 (Totals) 4	191	7517	183	7845

Key: (1) Observation Stations; 1181 Bozitan (Germany); 1873 Simeiz (USSR); 1893 Katsiveli (USSR); 1884 Rica (USSR); 1953 Santiago (Cuba); 7080 McDonald (USA); 7105 Kennedy Space Flight Center (US NASA Station); 7109 Quicy (USA, NASA Station); 7110 Monument Peak (USA, NASA Station); 7210 Haleakala (USA); 7236 Wuhan (China); 7308 Tokyo (Japan); 7834 Wettzell (Germany); 7835 Grasse (France); 7837 Shanghai (China); 7839 Graz (Austria); 7840 Greenwich (Britain); 7843 Orroral (Australia) (2) Passes (3) (NP Obs (4) Totals

Table 2 Precision estimation of ranging of 2 Etalon satellites

1 观测资料类型	2 资料日期	3 分析中心	4 分析圈数	5 估计精度
全部资料 (Full-rate) 6	1990 年 4 月—12 月	8 上海站预处理分析	73	8.2cm
快速资料 (Quick-look) 7	1990 年 9 月—12 月	NASA/GLTN	48	4.7cm

Key: (1) Types of material to be observed
(2) Dates of materials (3) Analyzing Centers
(4) number of passes (5) Estimated precision
(6) Total Materials (7) Quick-look Materials
(8) Pretreated analyses at Shanghai station

Table 1 gives a summary[3] of the global observation statistics during the synchronized observation period (September 1 of 1990 to December 1 of 1990) on Etalon satellites, distributed by Texas University CSR center. The number of passes observed by the Shanghai station and the number of standard points have all reached a high standard.

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Fig. 1 shows the actual measured residuals of Etalon-1 on August 13, 1990 at 11 O'clock (UTC). The "smooth" curve in the figure was formed by the densely arranged 4,138 echo signals. The dissipated points appearing at either side of the curve were noises. At the beginning and ending of the curve the scope of noise was larger, and this is due to the fact that when the tracking was started the ranging system was in the groping mode in searching for the targets and thus the distance gate was open rather widely. After the target was caught, the distance gate was compressed and noise was also reduced accordingly. At the middle section of the curve there is a gap, because to replace the data-recording soft-disks, the observer stopped tracking momentarily. Afterwards, by renewing the motion of tracking the above searching process was repeated. The entire observation process altogether covered 2 and one half hours and the average echoing rate was about 23%.

Table 2 provides the evaluation of ranging accuracy of the 2 Etalon satellites. Among them the pretreatment analyses by the Shanghai Astronomical Observatory were to eliminate obvious noises and to send out quick-look data. The steps of the required analysis should be referred to the literature[4]. Because the adopted satellite orbits to be used in the long-term time-table of the forecast report have not gone through any rigid orbital revision, the evaluation of the accuracy may be rather coarse. The quick-look data were 50 ranging points, selected from each pass evenly taken out of the distribution, and then by use of telecommunication they were sent to the U. S. National Aerospace Agency "Getate" Laser Tracking Network (NASDA/GLTN). This center would take the results of such preliminary analyses and send them out to all the observation stations by telecommunication, to find out any problem in the observations. Table 2 lists the precision estimation by the 2 centers for 2 kinds of data. All in all it is recognized that at present the ranging precision of this ranging system is about 5 - 7 mm. It is slightly lower than the ranging precision of Lageos (4 - 5 mm), and the main reason is due to the echo pulses of Etalon satellites which were weaker.

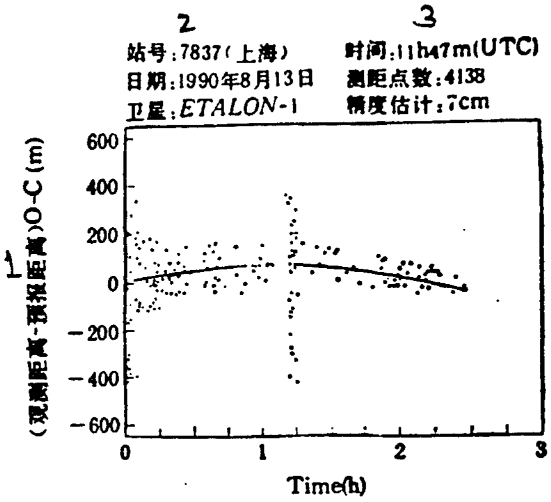

Fig. 1 The results of actual measurement on Etalon-1

Key: (1) observed range - Forecast range o-c (m)
(2) Station number: 7837 (Shanghai)
Date: August 13, 1990
Satellite: Etalon-1

(3) Time: 1 hr 47 min (UTC)
number of ranging: 4,138
Precision estimation: 7 cm

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