04-13-0214

Progress and Observation of Space Debris Laser Ranging System with high repetition rate laser at Shanghai Observatory

Zhang Zhongping, Zhang Haifeng, Wu Zhibo,Sun Hao, Li Pu, Meng Wendong, Chen Juping,Wu Bin
Shanghai Astronomical Observatory, Chinese Academy of Sciences
zzp@shao.ac.cn

Abstract: *Space debris becomes the vital factors threatening the safety of working spacecrafts on orbit. High precision measurement and accurate catalogue for space debris are required. Laser ranging is the kind of real-time measuring technology for space debris observation with the measuring precision of decimeters to help the precise orbit determination. During past several years Shanghai Observatory has built space debris laser ranging system with high pulse energy, low repetition rate, lamp pumped solid-state laser. Aiming at the international development trend of working mode of high power laser, Shanghai Observatory, for the first time in China, successfully applies the 50W power diode pumped solid-state laser system with 200Hz and low dark noise APD detector to observe space debris and many passes of laser data are obtained. The measuring results show that the laser observation system has good performances and measuring ability. In addition the continuous passes of some targets have been obtained during the experiment of orbit determination to space debris are carried out by using the laser measurement data from the single station and the preliminary results are also presented.*

1. Introduction

As the development of space technology in the world, more and more spacecrafts are launched into space and lots of space debris orbiting the Earth, such as rocket bodies, unused satellites, targets from collision between spacecrafts, are produced. Space debris has become the major problem for space-active nations and threatened greatly to the active spacecrafts in recent decade years. China has launched many spacecrafts into space since 1970s and been paying great efforts to reduce space debris in cooperation with international community and also developing kinds of high precise measuring techniques for the reliable and accurate catalogue of space debris to avoid collision. Among the techniques of observing space debris, laser ranging is one kind of real time measurement with the precision of meters or decimeters, one or two orders of magnitude higher than microwave radar. In the past years, several countries in the world, such as Australia, USA, Austria, France, have been doing the research on space debris laser ranging. As the new applications of laser ranging techniques, Shanghai Astronomical Observatory (SHAO) of Chinese Academy of Sciences (CAS) has been working on the laser ranging to space debris since 2006. The first experiment of laser ranging to space debris in China was successfully performed at SHAO in July 2008. During the past the several years, some improvements of laser system, detectors, control system have been performed and the ability of laser measurement to space debris is also increased obviously. The great achievements in 2013 have been made through adopting the high power laser system with 200Hz repetition rate and the power of 50W and APD low dark noise detector. From March and April 2013, many targets and lots of passes of laser data are obtained and the measuring results show that laser observation system has good performances. Among the laser measurement, the multi passes of laser data from some targets have been obtained and the chances of performing the experiments of orbit determination for space debris by using laser data from the single station were firstly given and carried out to validate the feasibility of the methods of laser data processing.

2. Space debris laser ranging system at Shanghai station

1) High power laser system

For laser ranging to space debris, the high power laser system with good beam quality, stability and pointing accuracy is very important, especially for observing space objects with long distance and small size. The lamp pumped laser system with low repetition rate was used during 2008-2012 at SHAO. Limited to its working mode, the performances of high stability, good laser beam quality with high power are very difficulty to be achieved while increasing its power, the enlarged pulse energy will make the optical components (laser system, optical coude path) more damageable.

So for the high power laser system, the best way to meet the power and not to damage the module of laser system is to increase the working frequency and to decrease the pulse energy. In order to test the measuring ability of high power laser at the high repetition rate mode, a set of the semiconductor pumped laser system with the power of 50W and 200Hz working frequency was installed at SHAO at the beginning of 2013. Figure 1 shows the optical principle of high repetition rate laser system. And figure 2 gives the high power laser system and laser beam.

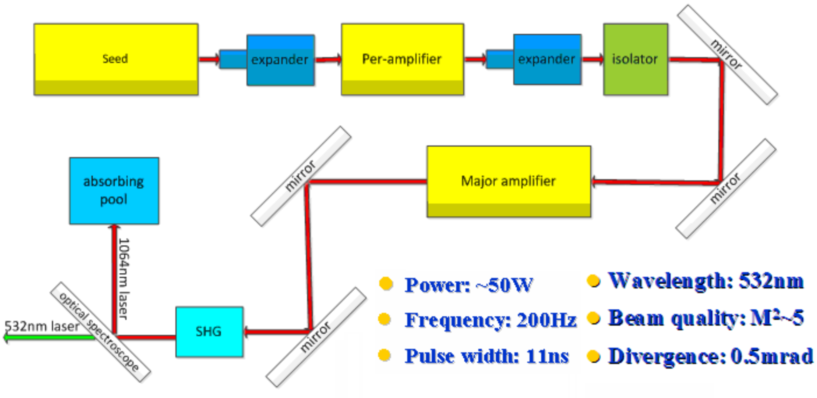

Figure 1 the optical principle of high repetition rate laser system

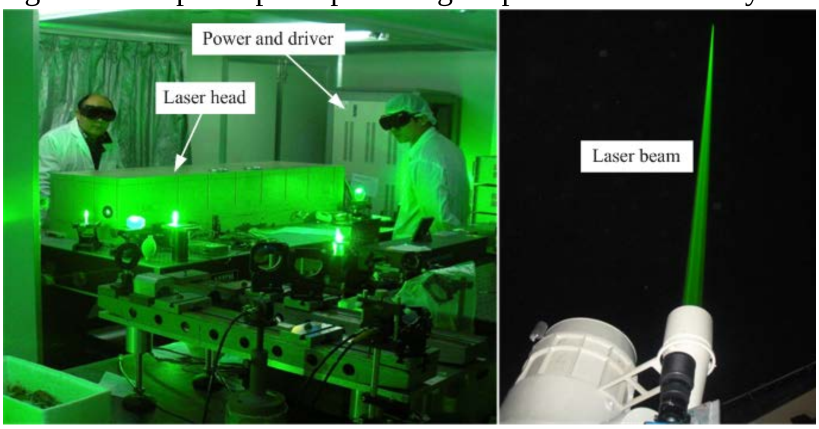

Figure 2 the high power laser system and laser beam

2) The low dark noise and high efficiency detector

The high power laser system helps to solve number of laser returns from space debris. But two key problems for laser measurement to space debris are still exist:1) not good precision of orbit prediction to make range gate control difficultly; 2) Noise from background and detector, especially for high repetition rate. So the keys is to reduce the level of noise detection to make large scale of range gate adjustment and obtain laser returns with high S/N for farther and smaller space debris.

The breadboard APD detector is developed by our group based on Compass LTT detector and cooperation with domestic university. Figure 3 shows the APD detector and its main performances. Replaced by this detector the laser measurements to space debris are performed.

By using APD detector, the dark noise can be decreased. But the noise from sky and targets also make some influences on the laser detection. For that, the high efficiency narrow bandwidth spectrum filter is adopted to reduce the level of background noise. The main characteristics of the filter are following:1) Center wavelength:532nm;2) Bandwidth:±1nm;3) Efficiency :>90%.

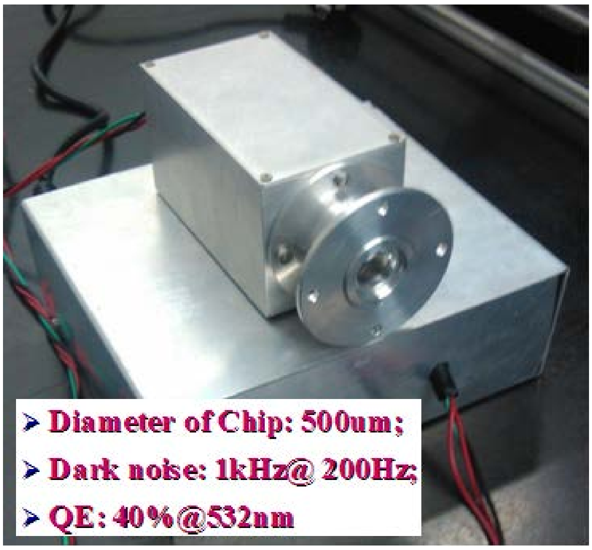

Figure 3 the breadboard APD detector and its main performances

3) The time interval instrument and the control system of laser measurement

The event timer Model A033-ET for time interval measurement with 10 psec timing precision made by the Riga University, Latvia is used. The control system of laser measurement is the same as the routine kHz SLR system.The tracking error of 60cm telescope is less than 1 arc second to meet the requirement of tracing to space debris targets.

3. The results of laser ranging to space debris by high repetition rate laser

After installation of 50W laser system at the repetition of 200Hz and making other improvements, the laser measurement to space debris are implemented for testing the ability of the laser system during March and April in 2013. The more than 110 objects (Rocket body, Iridium, Radar Cal. Obj, Debris) with 160 passes of laser data are obtained. And on April 2 the 16 passes at one night are obtained and among the measured objects the farthest range is more than 2100km and the min. cross section (RCS) is 0.5 m^2 and the measurement success rate is more than 80% for the large size of objects. Table 1 shows the statistic of laser measurement to space debris with the 50W laser system at the 200Hz repetition rate on April 2.

Table 1 the statistic of laser measurement to space debris on April 2, 2013

No.	ID.	Len. of Pass /min	RCS /m^2	Ranging /km	Returns	Precision /cm
1	11112	1.24	4.96	1178 ~1495	435	72.13
2	4237	4.09	1.02	1045 ~1465	177	59.34
3	23815	1.78	1.55	840 ~1096	181	53.46
4	17160	2.88	4.57	1011 ~1212	493	88.86
5	18749	2.39	4.59	655 ~1098	1025	66.71
6	2825	1.18	5.21	1154 ~1496	487	72.19
7	7737	2.56	2.99	1204 ~1456	61	99.32
8	8744	2.66	2.98	1067 ~1206	266	47.9
9	22699	1.77	0.8	883 ~1224	77	47.12
10	19120	3.23	10.72	875 ~1375	3753	57.42
11	1389	1.79	1	1245 ~1498	234	49.19
12	29956	4.09	0.51	966 ~ 1340	65	51.61
13	10246	2.26	0.82	566 ~ 937	300	55.92
14	1433	0.63	0.6	864 ~ 995	33	37.42
15	19910	6.11	6	1773 ~2160	118	72.87
16	13493	4.03	1.78	1259 ~1571	207	66.62

The comparison of measured objects at the distance and cross section by 30W@10Hz laser system in 2011 and 50W@ 200Hz laser system in 2013 are presented in figure4. From the measured results, the measurement success rate and cross section of measured objects is improved greatly after using the high repetition rate laser system. The measuring results also validate the good performance of high power laser with high repetition rate.

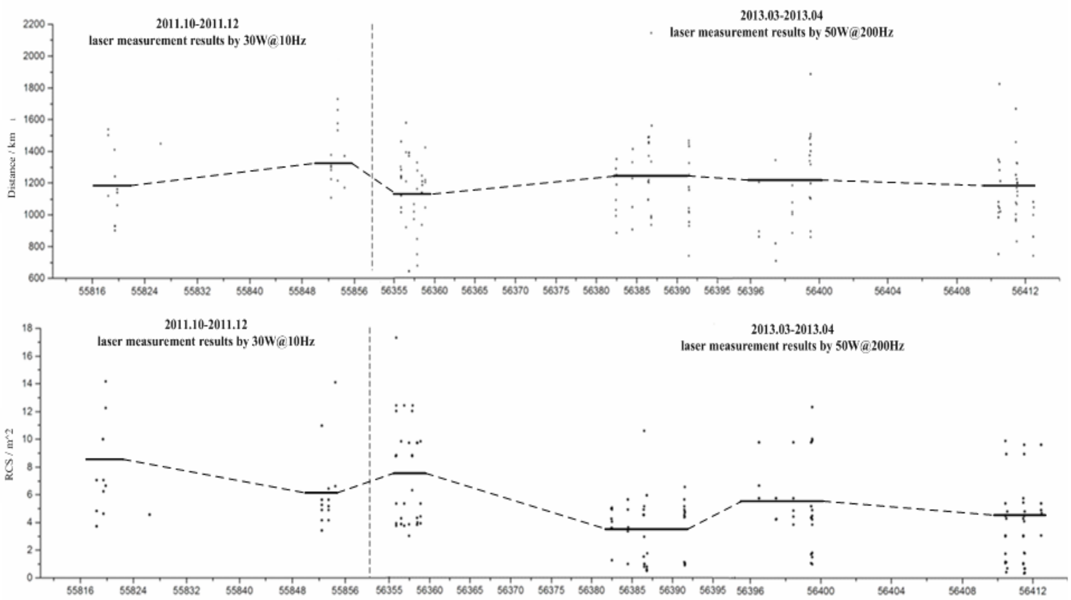

Figure 4 Comparison of laser measurement to space debris by 30W@10Hz and 50W@200Hz laser

4. Preliminary orbit analysis by laser data from the single station

Among the laser measurement to space debris from March and April 2013, several objects with multi passes of laser data in consecutive days are obtained (seeing the table 2) to meet the requirements of orbit processing and analysis.

Table2 the measured object with multi passes of laser data (March 2 and March 6)

NORAD ID	Start Time (UTC)	Arc Section (s)	Actual sampling Time (s)	Echoes	Average sampling rate (per sec)	Range (km)
20453	03-04 11:49:08	77	72	669	9	777～1179
	03-05 10:38:06	209	197	1629	8	
	03-05 12:21:57	101	99	1443	15	
	03-06 11:12:27	131	105	557	5	
28222	03-02 21:06:44	98	89	6010	68	571～1287
	03-03 21:06:39	30	30	893	30	
	03-04 21:07:55	104	98	3583	37	
11574	03-02 21:22:30	96	81	312	4	855～1317
	03-03 20:40:30	221	198	652	3	
	03-05 21:02:01	177	170	1638	10	
23705	03-03 11:04:27	257	65	101	2	871～1588
	03-05 21:23:26	31	27	101	4	
16182	03-02 21:16:29	228	218	2615	12	1248～1317
	03-04 20:45:24	149	148	2410	16	

Method of Orbit Determination (OD)

(1) No consideration of object size and correction of COM, just regard as to be a point.

(2) Orbit determination with some numerical models: 1) Gravitational field (GGM02C(150 x 150)); 2) N-Body (DE200 /DE403); 3) Bodily tide (IERS2003); 4) Sea tide (TOPEX3.0); 5) EOP(IERS EOP series); 6) Solar press and Albedo press; 7) Atmospheric drag (DTM94); 8) Marini-Murray; 9) Relativistic effect of Earth, Moon, Sun.

By using the above dynamics models, the orbit determination by laser data from objects (20453, 23343,11574,and 16182) can be convergent when data processing and results of orbit determination for the objects can be given by using laser data from single station. Through the comparison of range of the measurement and orbit calculation, the range residual (after orbit determination) is about 1-2 meters (seen from the figure 6), lower than laser measuring RMS (60-80cm).

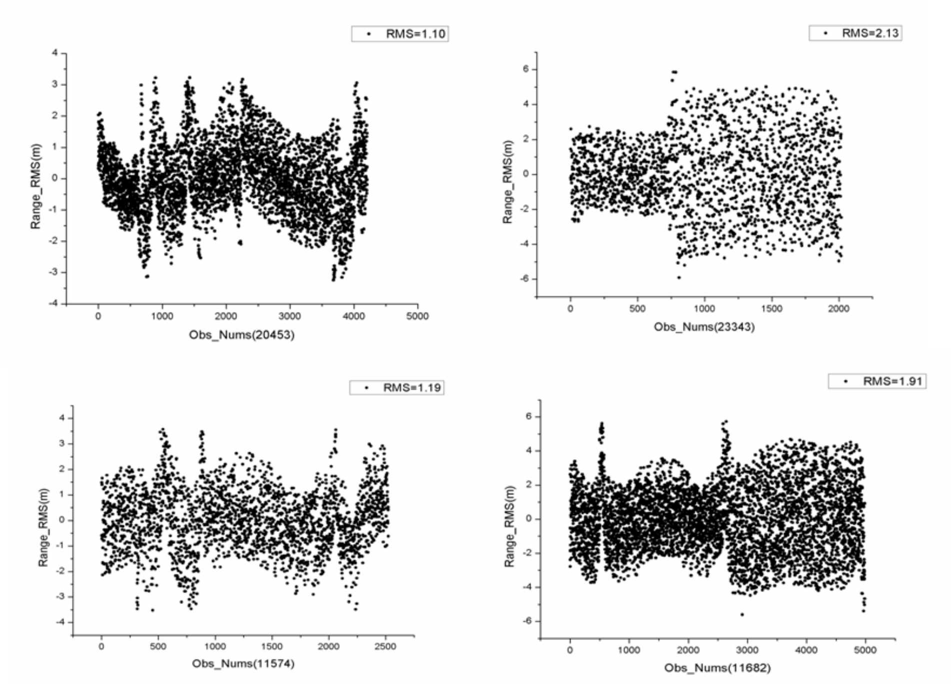

Figure 6 the range residual of the measurement and orbit calculation

Method of assessing orbit determination precision

Before assessing the orbit determination precision, the rationality of the results of orbit determination from laser data should be checked. Due to no other orbit, so TLE orbit are used. Through comparison of the results of orbit determination from laser data and TLE at the same time segment, the orbit error can be obtained. From the results, we think the orbit derived by laser data from the single station is validated and believable.

There are total four passes of laser data from March 2 to March 6 for the objects (20453), and the requirement of orbit overlap data processing is met to assess the accuracy of OD. We use the fore three passes of laser data, the last three passes of laser data and the total passes of laser data respectively to produce three orbits (Orbit_1, Orbit_2, Orbit _3) and the three overlap orbit can also be calculated (Orbit Overlap_1 between Orbit_1 and Orbit_2, Orbit Overlap_2 between Orbit_1 and Orbit_3, Orbit Overlap_3 between Orbit_2 and Orbit_3). The results of orbit overlap can be seen from the table 4 and the accuracy of objects orbit produced by multi passes of laser data from a single station is less than 50m.

Table 3 the results of orbit bias by the method of orbit overlap

Orbit Overlap	Start Time (UTC)	Num of Passes	Length of OD/day	Length of overlap/day	Orbit bias /m			
					R	T	N	3D
1	03-04 11:49:08	3	1.5	1.0	7.13	31.16	17.41	36.41
	03-05 10:38:06	3	1.5					
2	03-04 11:49:08	3	1.5	1.0	11.72	39.45	17.98	44.92
3	03-05 10:38:06	3	1.5	1.0	4.64	12.39	0.96	13.27

Again to process laser data from objects (20453), adopting the fore three passes of laser data to produce the orbit and then using the results of orbit to predict for next 12 hours, covering the forth pass of laser data. So the range residual between measurement and predict can be calculated (seeing the table 5). From the results, the precision of the range residual (RMS) is the less than 300m.

Table 5 The accuracy of orbit prediction from laser data

Orbit determination			The laser data for comparison	Range residual (O-C) /m	
laser data (UTC)	Length of orbit (day)	Length of predictions (day)		Mean	RMS
03-04 11:49:08 03-05 10:38:06 03-05 12:21:57	1.5	0.5	03-06 11:12:27-11:14:38	229.98	177.92

5. Conclusion

The laser ranging to space debris in China was successfully performed at the Shanghai Observatory in July 2008. For increasing the ability of measuring space debris, the upgrades of laser ranging system are continually implemented. In 2013 the 200Hz repetition rate laser at the mode of diode pumped, 50W power was firstly applied to track space debris in China and the breadboard APD detector and high efficiency spectrum filter has also been developed and used. Based on the improved laser measurement system, the measuring ability is increased greatly. Among the laser measurement to space debris, the min. cross section (RCS) reaches to $0.5m^2$ and the farthest is more than 2100km and the measurement success rate over 80% for large size objects. Finally through using multi consecutive passes of laser data from a single station, the experiment of orbit determination have been performed and the accuracy of orbit determination for space debris from laser data is less than 50m derived from the method of orbit overlap and the precision of orbit prediction by laser data from the single station is less than 300m for predicting 12 hour. However, the results of orbit determination are only given by one object and the laser data from more objects are needed to further validate it.

Acknowledgements This research is supported by the Instrument Developing Project of the Chinese Academy of Sciences (Grant No. 2920100701), the projects of space debris research from the State Administration of Science, Technology and Industry (Grant No. K0103110).

References

Greene, Ben, Yuo G., Chris Moore et al. Proceedings of the 13th International Laser Ranging Workshop, Washington, USA, 2002, 13, 198

Yang Fumin, Zhang Zhongping, Chen Juping, et al. Preliminary results of laser ranging to uncooperative targets at Shanghai SLR station. Proceedings of the 16th International Laser Ranging Workshop, Poznan, Poland, 2008, 16,695

Zhongping Zhang, Fumin Yang, Haifeng Zhang, et al. The use of laser ranging to measure space debris. Research in Astron. Astrophys. 2012, 12(2), 212

Artyukh Yu. Proceedings of the 16th International Laser Ranging Workshop, Poznan, Poland,2008, 16, 398

Degnan, J.J. Contributions of Space Geodesy to Geodynamics: Technology, Geodynamics Series, 1993, 25, 133