21st International Workshop on Laser Ranging
«Laser Ranging for Sustainable Millimeter Geoscience»
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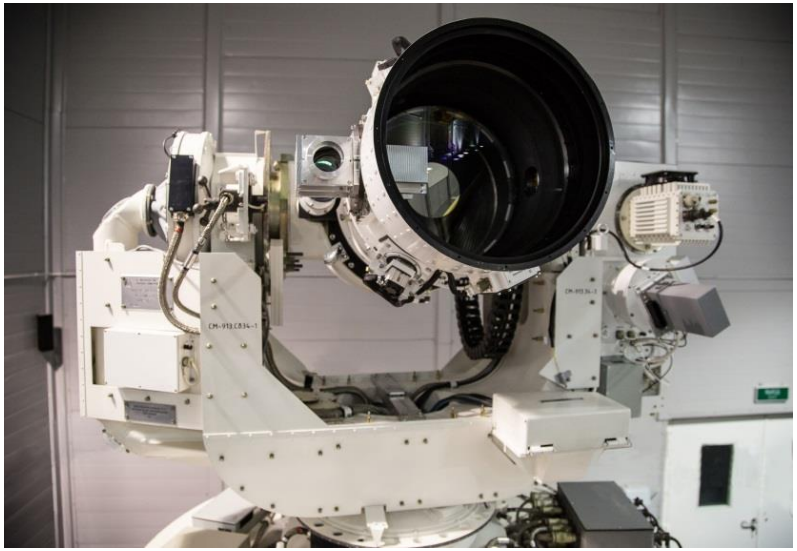
THE RESULTS OF FULL-SCALE TESTS OF THE NEW RUSSIAN LASER STATION «TOCHKA»



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Agenda

1. **Laser station «Tochka»: purpose and installation aspects;**
2. **Experimental evaluation of how accurate the station's automatic laser beam pointing system is under both night and daytime conditions;**
3. **Experimental evaluation of the station's output performance;**
4. **Experimental evaluation of instrumental precision of single-shot range measurements and of how accurate the station's calibration is;**
5. **Experimental evaluation of how accurate multiple range measurements are under both night and daytime conditions;**
6. **Experimental evaluation of how accurately laser pulses are linked to an external time scale in precision time transfer mode.**

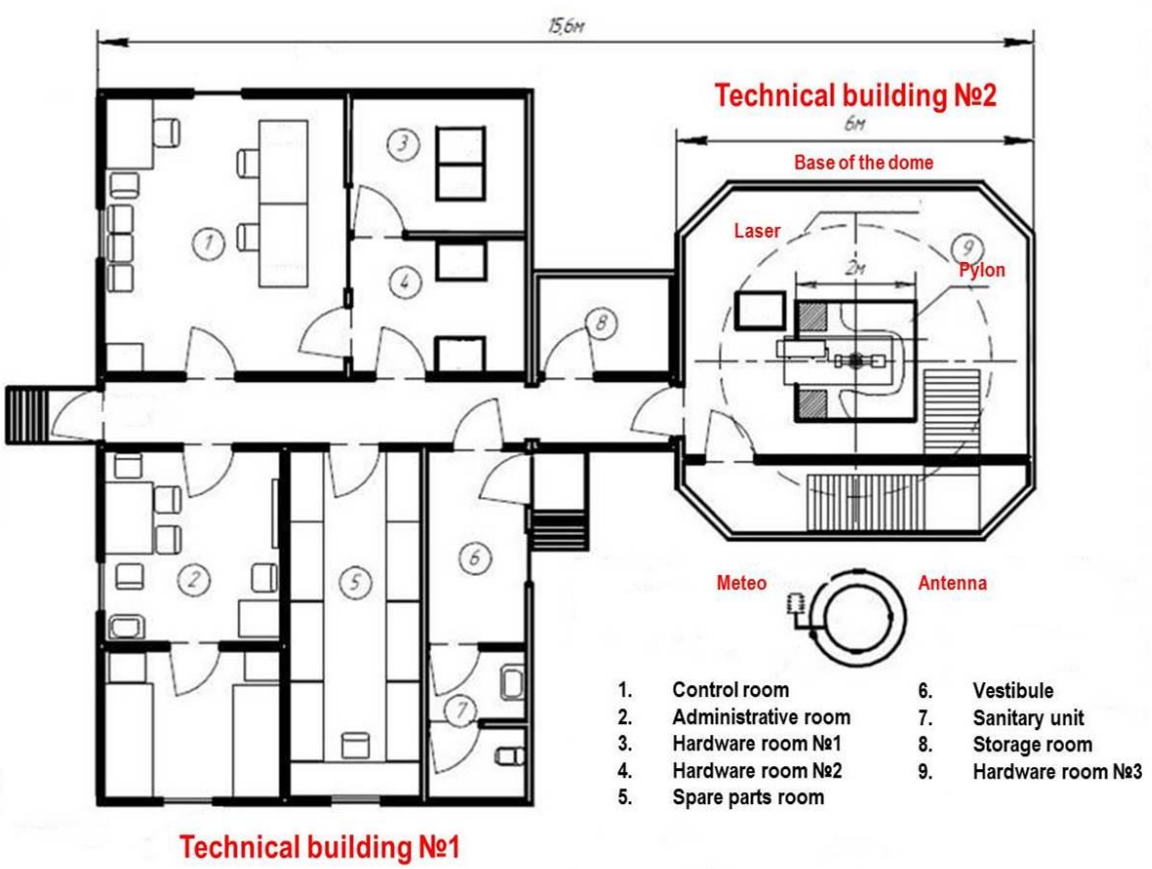
Purpose of the laser station «Tochka»

The laser station «Tochka» takes 3 kinds of measurements at once: precision laser ranging, precision laser pseudoranging to the NSC «Glonass» and radiofrequency pseudoranging by navigation signals from the SC «Glonass».

In late 2017, the first-ever station «Tochka» was installed at the Mendeleyevo operating site. Over 2018, the station has been successfully passing the full-scale tests.

Station deployment

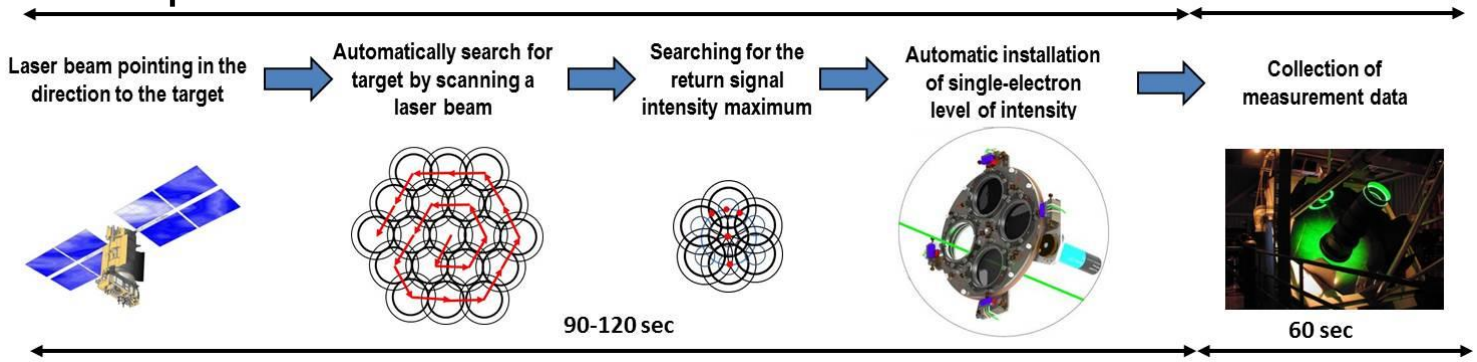
The laser station is deployed at an operating site of 20 x 16 m in size. The station's equipment is setup in two adjacent technical buildings.



The total power consumption of both the station's and engineering equipment packages does not exceed 45 kW. The power is supplied using a 220V/50Hz AC network.

Experimental evaluation of how accurate the station's pointing system is under different conditions

The laser station «Tochka» implements the technique of «blind» pointing at a target satellite using the given target designations where neither the target itself nor a scattered laser beam track can be seen directly by the station's TV cameras. The «blind» pointing technique allows us to make the process of taking measurements fully automatic under both night and daytime tracking conditions once the calibration by stars has been completed.

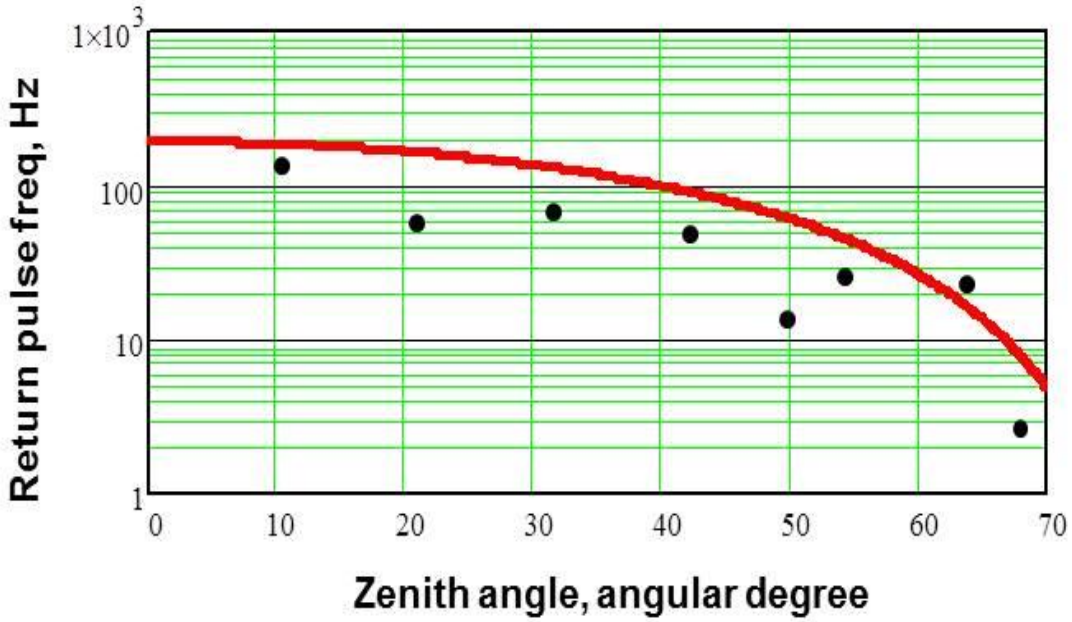


Overall performance of the auto-pointing mode used under both night and daytime conditions was evaluated through logging the time checkpoints at which the system had locked-on the SC «Glonass» and further calculating an average lock-on time by a series of sessions. Additionally, the pointing accuracy by stars was regularly monitored.

Pointing accuracy	Average time to lock-on a target	Time it takes the pointing accuracy to go down
< 10 arcsec	22 sec	7 days
< 20 arcsec	75 sec	3 months

Experimental evaluation of the station's output performance

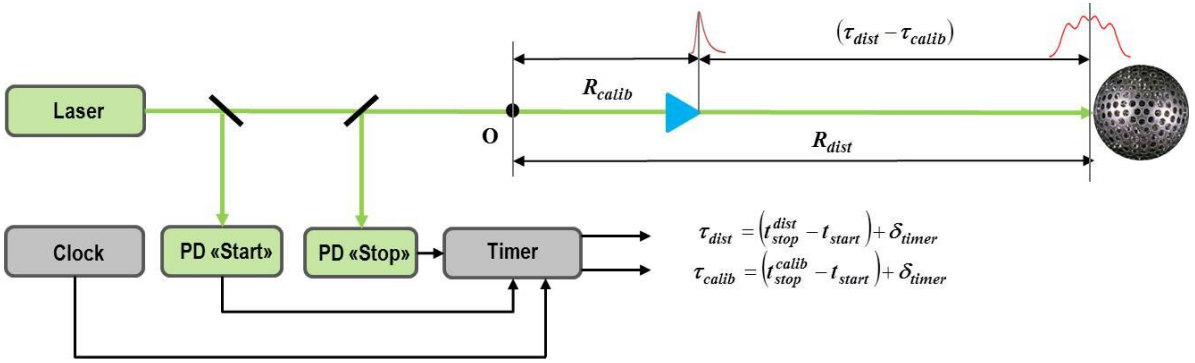
The station's output performance has been experimentally evaluated by the rate and number of return pulses per session when tracking the SC «Glonass» whose retroreflector systems always have a single-electron response.



In general, the results of the sessions taken under near-calculated conditions show a satisfactory agreement between the calculated and experimental data volumes.

Experimental evaluation of instrumental precision of single-shot range measurements and of station's calibration accuracy

To achieve a submillimeter error of measurement by both random and systematic components, «Tochka» takes range measurements in differential mode.



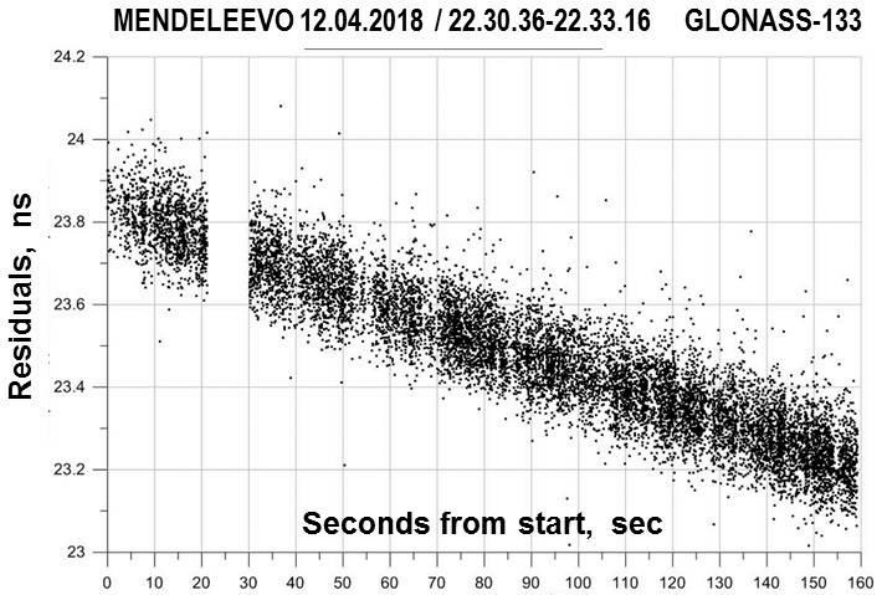
The instrumental random error of the station with single-shot range measurements has been evaluated by the spread of measurements at the calibration distance.

Error of single-shot range measurements	Systematic error of hardware correction determination	Random error of hardware correction determination	Hardware correction value
9.8 mm	< 0.5 mm	< 0.2 mm	27736.3 mm

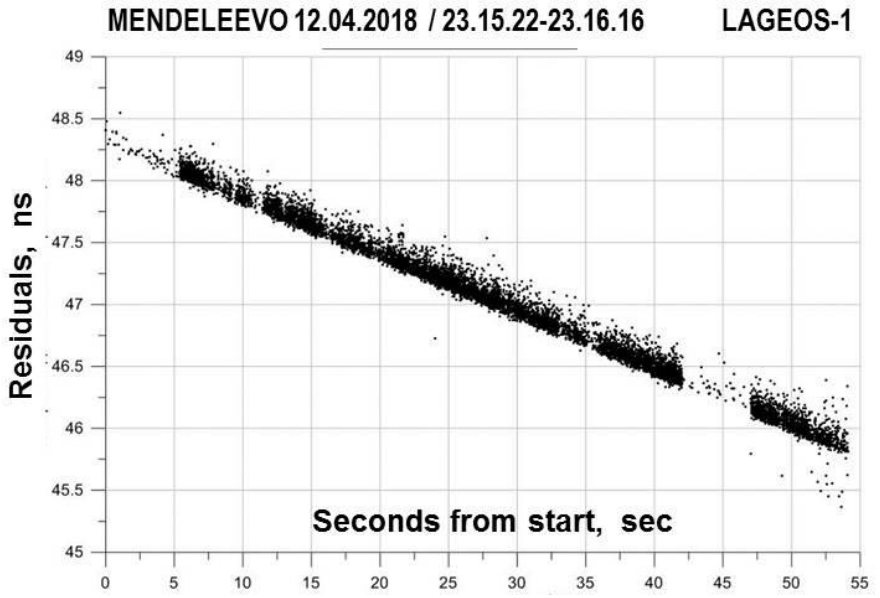
The instrumental error of single-shot range measurements does not exceed 10 mm while the hardware correction determination error does not exceed 0.5 mm by the systematic component and 0.2 mm by the random component, respectively, with the measurement averaging time of 60 sec.

Experimental evaluation of accuracy of multiple range measurements taken at night

Ranging accuracy has been evaluated by the SC «Glonass» and «Lageos». The charts show the discrepancies of typical measurements of ranges to the SC «Glonass» and «Lageos» taken at night.



Avg. response rate	Measurements per minute	RMS of single-shot measurements	NP RMS
76 Hz	4615	19 mm	0.28 mm

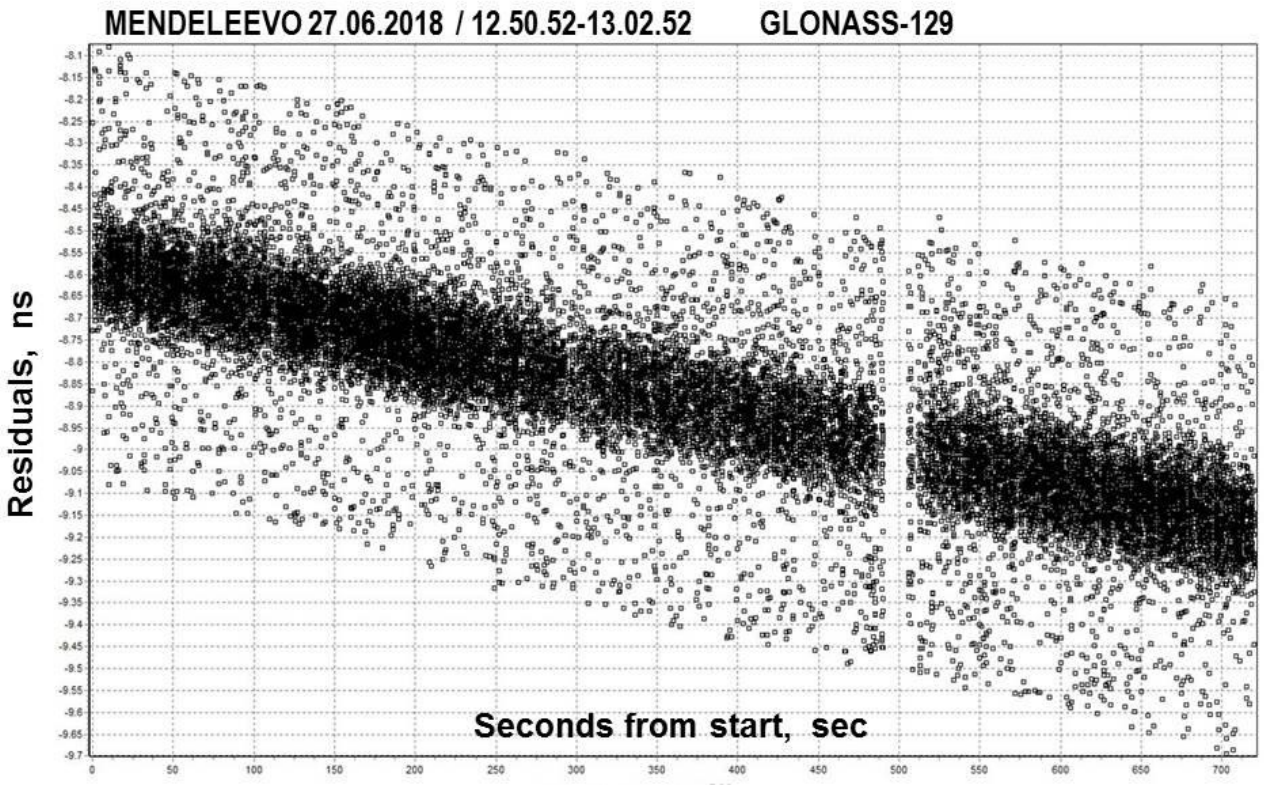


Avg. response rate	Measurements per minute	RMS of single-shot measurements	NP RMS
149 Hz	8951	13 mm	0.14 mm

The accuracy of the normal points built on these measurements on a 60 s interval was 0.28 mm with a number of measurements of about 4,500 and 0.14 mm with a number of measurements of about 9,000, respectively.

Experimental evaluation of accuracy of multiple range measurements taken by day

The chart below illustrates a typical result of daytime ranging to the SC «Glonass» over the course of a session of 720 seconds (12 minutes) in length and at elevation angles of about 35-41° and clearly shows false range measurements caused by the daily sky background.

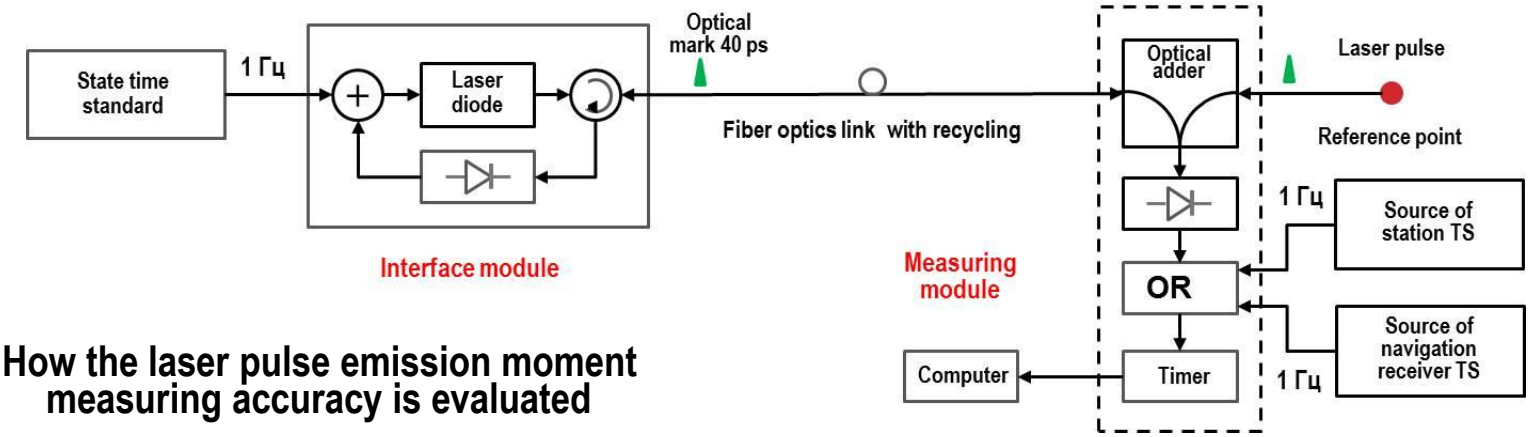


#	Number of NPs	Measurement RMS	NP RMS
1	2049	21.1 mm	0.465 mm
2	2060	22.5 mm	0.495 mm
3	2158	20.9 mm	0.451 mm
4	2125	21.6 mm	0.470 mm
5	1443	23.8 mm	0.627 mm
6	1434	24.1 mm	0.636 mm
7	1432	24.2 mm	0.638 mm
8	1330	25.8 mm	0.708 mm
9	1122	39.1 mm	1.181 mm
10	1944	24.2 mm	0.549 mm
11	2031	23.9 mm	0.532 mm
12	1631	23.7 mm	0.586 mm

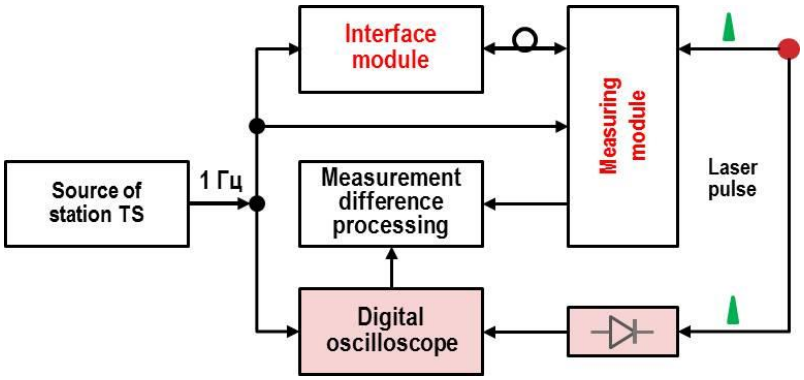
Upon processing the session was split into 12 NP with the duration of 60 seconds each.
The accuracy of almost all NPs is under 1 mm.

Experimental evaluation of how accurately laser pulses are linked to an external time scale while in precision TT mode

To use the time transfer function, the station takes extra accurate measurements of pulse emission moments in both the station's and STFS (external) time scales. The measuring subsystem consisting of the interface unit generating optical time tags, a fiber-optic line and the measurement unit enables taking measurements of a total delay of optical time tags in both the interface and measurement units every second in auto-mode.



How the laser pulse emission moment measuring accuracy is evaluated



Emission moment measuring error	Station's TS	External TS
Random error component (L=2 km)	12 ps	13 ps
Systematic error component (L=2 km)	17 ps	23 ps
Systematic error variations when the length changes from 80 m up to 2 km	-	6 ps

Laser pulse emission moments in both the station's and external time scales are determined with a systematic error of no greater than 25 picoseconds and a random error of no greater than 13 picoseconds.

Conclusions

1. Full-scale tests have confirmed the estimated characteristics of the laser station «Tochka», including but not limited to its output performance, possibility to make the process of laser beam pointing at a target fully automatic and ranging under both night and daytime conditions at a submillimeter level of accuracy.

2. The instrumental error of single-shot range measurements does not exceed 10 mm, while the error of multiple range measurements taken over 60 s intervals does not exceed 1 mm in the vast majority of cases.

3. To implement precision time transfer through the GLONASS system, the station measures laser pulse emission moments in both the station's and external time scales with a systematic error of no greater than 25 ps and with a random error of no greater than 13 picoseconds which, with due consideration of on-board equipment errors, lay the groundwork for remote time transfer using an on-board laser signal receiver (like those at the SC «Glonass») with an error of no greater than 100 ps.

THANK YOU FOR YOUR ATTENTION!