

Load Test Report

Moscow Exchange Trading & Clearing Systems

17 April 2021

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Testing objectives

1. To verify the trading and clearing systems operation under conditions of peak loading and an increased number of orders and trades. The trading systems of the following Moscow Exchange's markets were tested:
 - a. Securities Market
 - b. FX Market
 - c. Derivatives Market
2. To estimate the time of order filling and data delivery from the trading and clearing systems at different load levels and software and hardware configurations.
3. To allow third party software developers and brokers to test their systems and estimate the throughput capacity of communication channels to the exchange venues.

List of participants

In accordance with the Moscow Exchange IT committee's recommendation, the list of load testing participants will be published on exchange's website at moex.com.

Main results

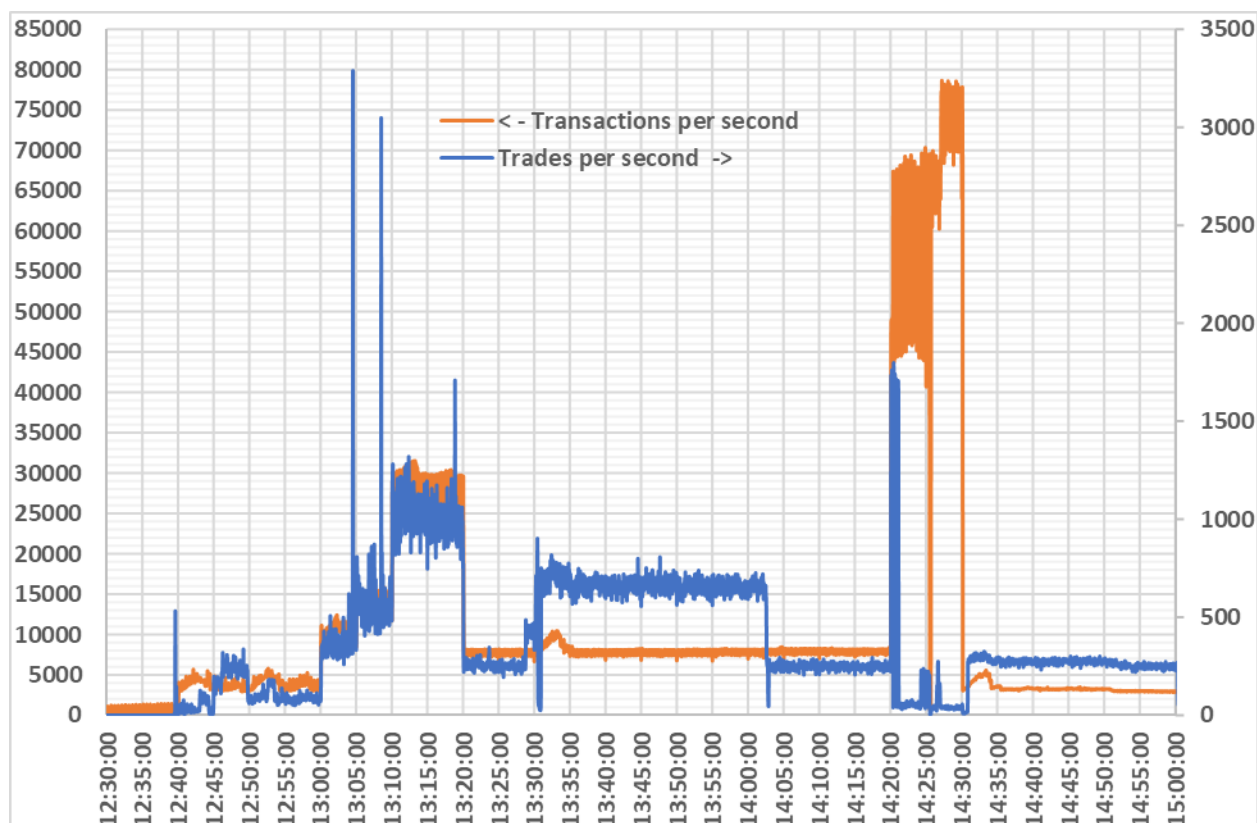
The Equity & Bond Market trading and clearing system

The testing was carried out on the production version of the system with independent trading and clearing engines. Server configuration used during the tests was the same as it was expected to be in production.

The table below shows comparative performance in testing in 2020. The 'accepted transactions' term means all the incoming transactions that led either to order registration or to successful cancelation of an order.

	Transactions	Orders	Trades
Values reached (units), 2021	112 607 811	62 749 115	4 220 823
Values reached (units), 2020	159 625 411	82 011 382	5 182 189
Max processing rate for accepted transactions (units per sec), 2021	79 028	39324	3288
Max processing rate for accepted transactions (units per sec), 2020	74 636	38 070	1740
Performance growth 2021 to 2020	+ 6%	+3%	

The graph below shows the frequency of transactions, orders, and transactions by clients – testing participants. The maximum system performance level was not reached during the load test.



The share of client generated activity was 3.6% of all transactions in 2021, that is significantly lower than their share in 2020 (28%).

The peculiarity of testing scenario in 2021 is generation of activity by 400 instruments simultaneously. This value corresponds to forecast of an increase in the number of actively trading instruments in the near future.

From 14.20 to 14.30, the transaction generator emitted transactions with variable frequencies. The average speed of transaction flow was 60,000 tran/sec, up to multiple times higher than the actual production one-second activity peaks (up to 7,500 tran/sec and 99.9% of one-second intervals with activity less than 2,300 tran/sec).

The peak frequency was generated in the repetitive intervals with durations of approximately 5 seconds. Unlike the permanent peak load, this scenario allows to measure recovery time needed for some components of the trading system whose ability to function normally was interrupted by peak load. A stress nature of the load testing was remained.

The insignificant capacity increase of the Equity & Bond Market trading and clearing system by 3-6% comparative to 2020 testing results is within the measurement accuracy.

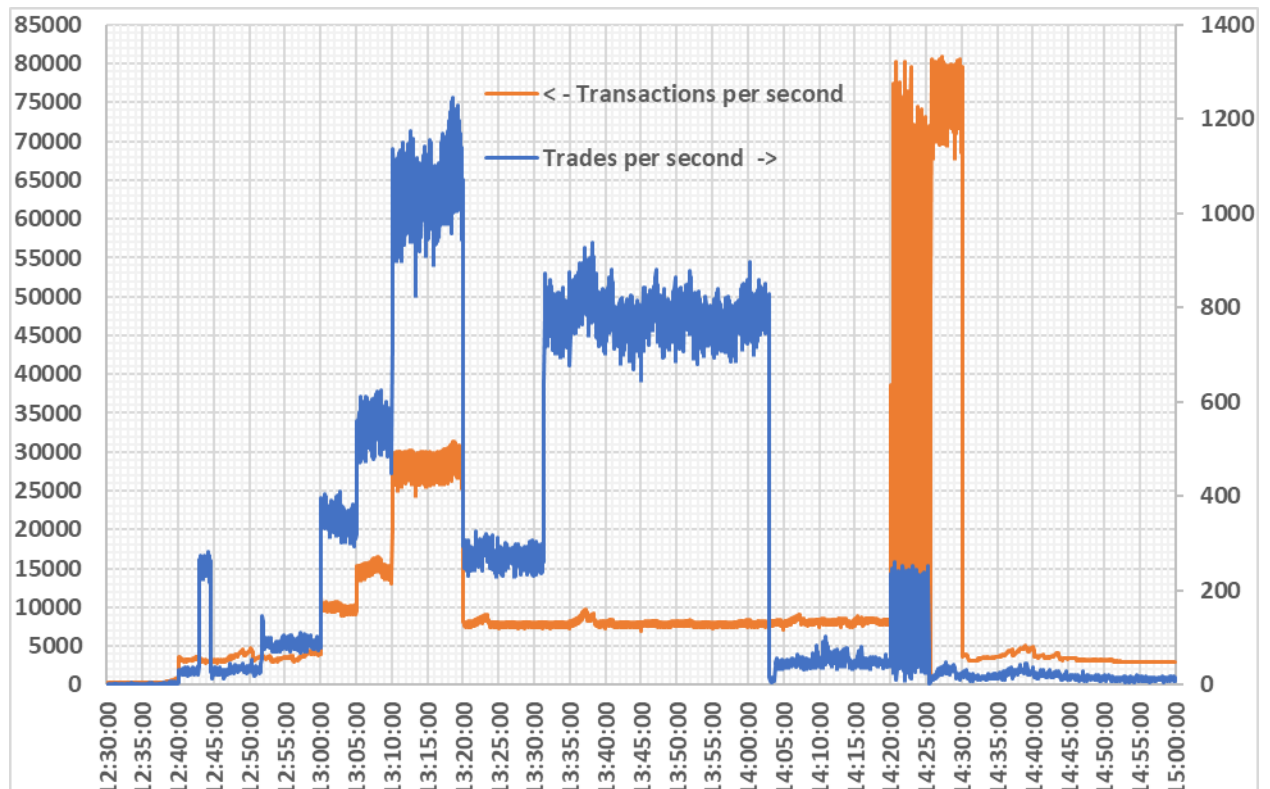
The FX Market trading and clearing system

The testing was carried out on the production version of the system with independent trading engine and several independent clearing engines. Server configuration used during the tests was similar to that expected to be in production.

The table below shows comparative performance in testing in 2020. The 'accepted transactions' term means all the incoming transactions that led either to order registration or to successful cancelation of an order.

	Transactions	Orders	Trades
Values reached (units), 2021	107 480 432	55 173 416	2 878 998
Values reached (units), 2020	118 962 847	60 538 374	2 606 363
Max processing rate for accepted transactions (units per sec), 2021	81479	40 730	1245
Max processing rate for accepted transactions (units per sec), production configuration, 2020	76390	39050	2742
Performance improvement, 2021 / 2020, %	+6%	+4%	

The graph below shows the frequency of transactions, orders, and transactions by clients – testing participants. The maximum system performance level was not reached during the load test.



The share of client generated activity was 3.7% of all transactions that is significantly lower than the client share in 2020 (25%).

From 14.20 to 14.30, the transaction generator emitted transactions with variable frequencies. The average speed of transaction flow was 38,000 tran/sec, up to multiple times higher than the actual production activity peaks (up to 6,000 tran/sec and 99.9% of one-second intervals with activity less than 3,000 tran/sec).

The peak frequency was generated in the repetitive intervals with durations of approximately 5 seconds. Unlike the permanent peak load, this scenario allows to measure recovery time needed for some components of the trading system whose ability to function normally was interrupted by peak load. A stress nature of the load testing was remained.

The insignificant capacity increase of the FX Market trading and clearing system by 3-6% comparative to 2020 testing results is within the measurement accuracy.

The Derivatives Market trading and clearing system

The testing was carried out on the SPECTRA system version 6.8 used in production since 10 April 2021 on the servers of the main Data Space and M1 data centers.

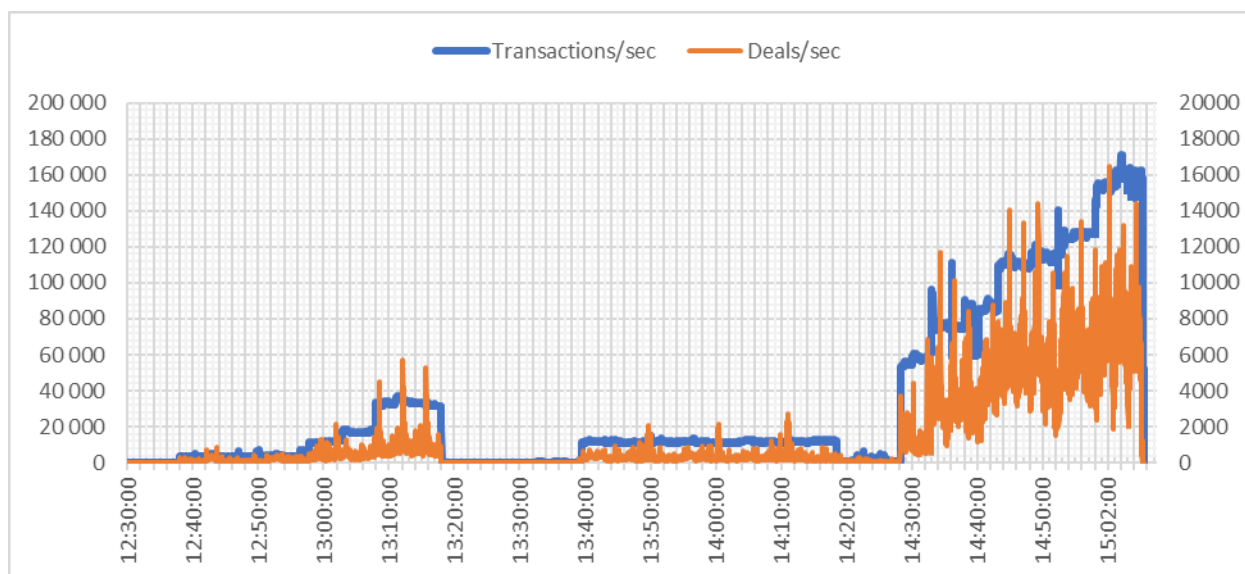
The ratio and load profile of transactions submitted over the different protocols was similar to the production.

The order-to-trade ratio in the testing was also near the production value. 281 million transactions were sent, and 12.2 million trades were executed during the testing. The peak performance was 171,000 transaction/sec with the stable trading system performance at average speed of around 150,000 transaction/sec.

	Transactions	Orders	Trades
Values reached (units), 2021	281 270 523	144 870 693	12 253 444
Values reached (units), 2020	278 508 915	196 000 000	10 696 865
Max processing rate (units per sec), 2021	171 000	-	-
Max processing rate (units per sec), 2020	182 000	-	-
Max processing rate, real trading (units per sec), 2021	25 000		

Decrease of max processing rate comparative with the testing in 2020 is induced by the significant complication of order matching algorithm. The algorithm was updated as a part of the implementation of the synthetic matching new functionality in the release of SPECTRA 6.5.

The graphs below show a transaction load on the Derivatives Market trading system. Clients participating in testing generated 2.85% of the transactions.



During the tests, we carried out the scheduled intraday clearing session. Clearing was performed as usual, but it was out of the established time frames for 11 minutes. The reason of longer intraday clearing operating was that adapters for receiving data about orders and trades of Derivatives Market Backoffice were not configured optimally. Updates to optimize the configuration are planned according to the releases schedule.

ASTS Gateways

Equity & Bonds Market ASTS gateways as well as gateways of the FX market installed at both Data Space and M1 data centers were functioning correctly.

During the tests, there have been actively used client connections based on the new version of ASTS Bridge with enlarged maximum size of requests to information responses. ASTS Bridge software has functioned correctly across the whole range of transaction frequencies.

During the normal operation of the Equity and FX markets systems, the clearing gateways will only be available at the main data center. The clearing engine located at the backup facility works in a slave mode and will only serve clearing gateways in case of the main data center failure and migration of the trading engine to the backup facility. This scenario was not included into the load test program. The migration had been tested successfully in 2020, during the Disaster Recovery.

The clearing gateways were functioning correctly at a constant transaction flow rate of up to 38,000 transactions per second. When this threshold was being exceeded, there were delays in clearing data refreshes at gateways as compared to the main clearing engine. In real trading, the peak frequencies of more than 38,000 transactions per

second happen only in short bursts, so the expected delays will not exceed 5 milliseconds.

The FIX gateways configuration for both FX and Equity markets was similar to its production version. The gateways functioned normally across the whole range of transaction frequencies.

SPECTRA Gateways

Before the main load test there had been generated 15 million orders and 1 million trades to carry out mass connection tests and verify Late Join servers operate under conditions of active trading in evening session.

During the mass connection test the low client activity was registered.

200 bots simulating a full load of data on orders and trades from trading participants were used for testing as well as 10 client connections.

The mass connection test showed that the computing resources of the Late Join servers will be sufficient in the case of active trading in an evening session.

During the load test, no deviations from the normal gateways performance was registered. The FIX/TWIME and Plaza2 gateways configuration was similar to its production version. The TWIME gateways functioned normally across the whole range of transaction frequencies.

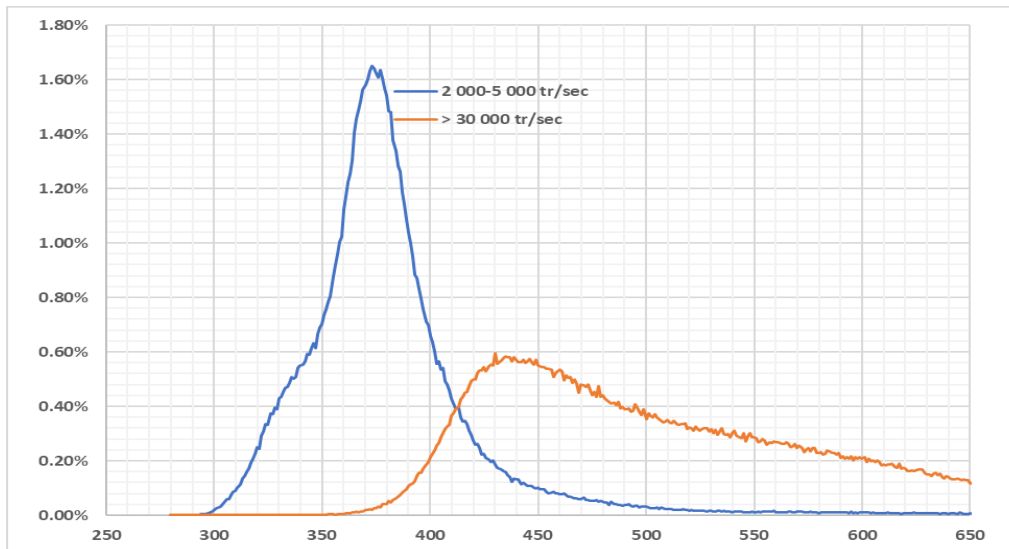
The Plaza2 virtualized gateways functioned normally until the exhaustion of virtual environment, when load of 30,000 transactions per seconds was reached.

Latency for transactions

Equity & Bond Market and FX Market trading systems

Transaction generators at the Exchange side were using Linux version of the embedded ASTS Bridge (libmtesrl.so library) or FIX protocol. These generators had been set up on a server connected to the trading network. Latency data for the FIX protocol for Equity and FX Markets was collected using the network monitoring system based on Corvil solution and customized for ASTS FIX messages.

To estimate latencies for the FIX protocol for Equity and FX markets, data collected by Corvil solution was processed. Below is the screen that shows statistic data on replies to FIX transactions for the Equity and FX Markets.

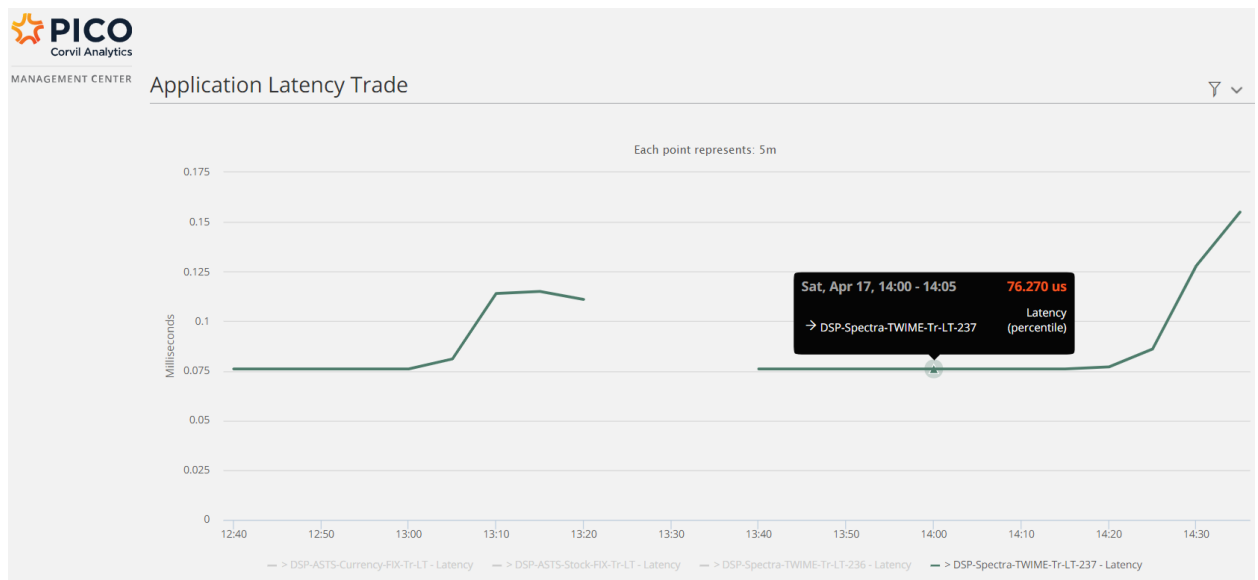


Presented graphs for FX and Equities markets are similar. Distributions of latencies for ASTS Bridge transactions are shifted by 60 microseconds approximately.

FIFO MFIX Trade latency data was not collected due to the absence of the load generator in one of the network segments.

Derivatives Market trading system

The internal Spectra monitoring system, Corvil solution and log files for client transactions have been used to measure the Derivatives Market latency.



Within the range from 3,000 to 65,000 transactions per second, the average RTT for TWIME gate was changing from 75 microseconds to 150 microseconds. However, RTT's growth for the frequencies of over 65,000 was induced by the rising load on the trading system core.

FIX/FAST UDP multicast marketdata of the Equity & Bond Market and FX Market

Before load test there was planned update of FAST servers' software for Equities and FX markets. FAST service for Equities market has started operating normally after 13.50 because of incorrect configuration.

Equity and FX markets FAST servers' configuration was the same as in production. The servers have operated correctly at all load levels during the test.

Statistical data on new order messages from the trading system (OLR feed, 279=0) relative to FIX protocol order accepted messages (Execution Report / 150=0) has been collected using the Corvil equipment. This data is being constantly collected during the normal trading.

For the FX Market, at maximum transaction frequencies, the average relative publication times increase to 50 and 160 microseconds, respectively.

UDP multicast traffic for the FX market reached the following values in each of copies A and B:

Feed	FX market, Mbps	Equity market, Mbps
Active orders (OLR)	20	14
Market statistics (MSR)	27	27
other feeds	2	2

Participants connecting to the service via data distribution channels are recommended to carefully select their subscriptions to data feeds and consider the network bandwidth as the total combined traffic of the two FAST lines of the FX Market and Equity& Bond Market in copies A and B may reach 500 Mbps.

In the production environment, the short FAST traffic bursts would most probably correspond to the network requirements stated above.

Recommendations given at <http://www.moex.com/a1160> are applicable to each FAST line.

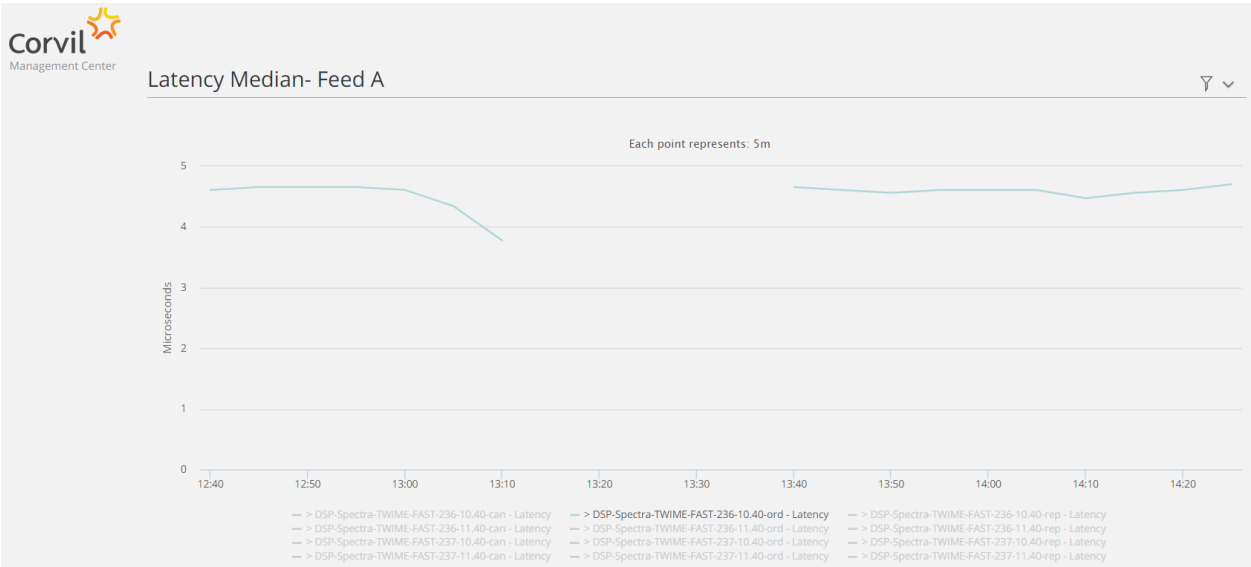
FAST UDP multicast marketdata servers of the Derivatives Market

The Derivatives Market FAST servers' configuration was the same as in production. The servers have operated correctly at all load levels during the test.

Statistical data on new order messages from the trading system (Full order log) relative to TWIME protocol order accepted messages (Execution Report) has been collected

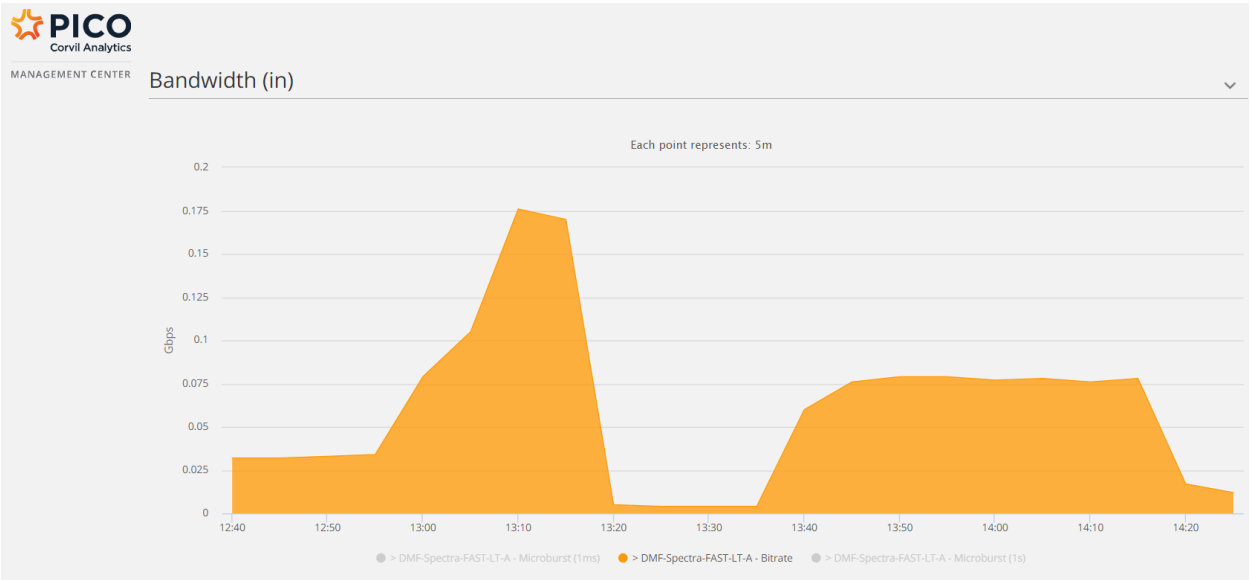
using the Corvil equipment. This data is being constantly collected during the normal trading.

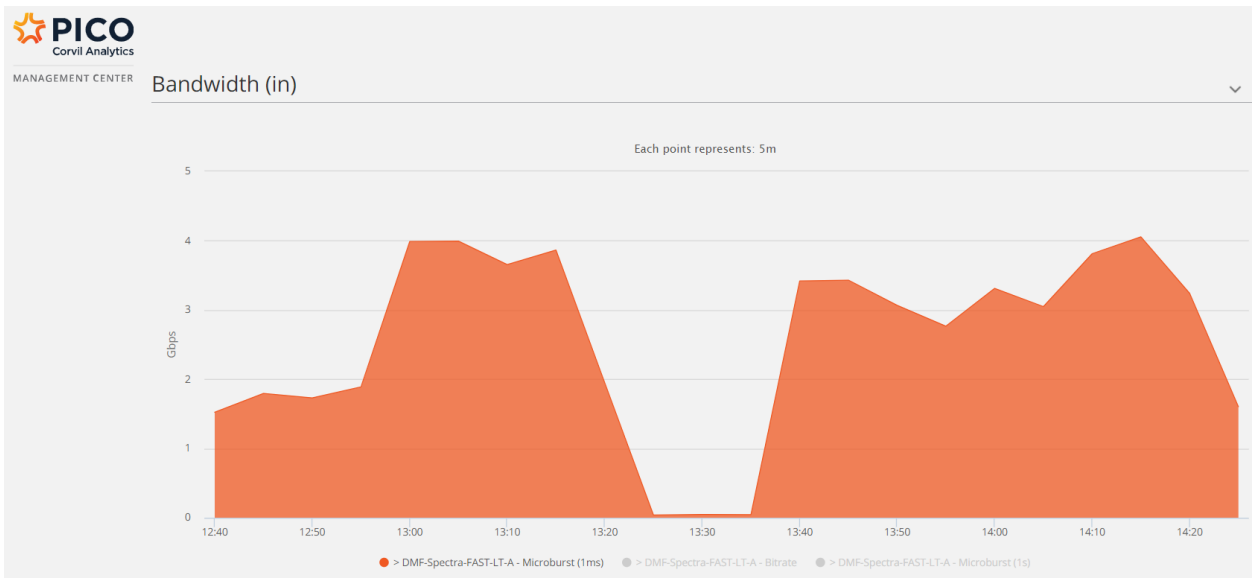
The average time of publication in the FAST feeds is shown in the screen below (the intermission on the graph was caused by the intermediate clearing session).



UDP multicast traffic for the Derivatives Market reached 175 Mbps in each of copies A and B with bursts of up to 4 Gbps.

Average publishing latencies at transaction frequency of up to 50,000 tran/sec were 4-5 microseconds.





The required network bandwidth for clients who wish to use the FAST service to receive ORDERS-LOG is minimum 100 Mbit/sec per feed. To receive two feeds, FEED A and FEED B, or data from more than one market, the 1-10 GBit/sec bandwidth is recommended.

At the present time, there are 2 modes to broadcast data on aggregate order-books: separated topics for futures and options operating as backwards compatible; and joint-topics mode for whole Derivatives Market launched in SPECTRA 6.5 release. Reason of traffic bursts appearance is multiple incremental updates for aggregate order-books during synthetic matching under conditions of multiple breaking through price levels. Separated topics are planned to be decommissioned at the end of June 2021 and then we expect decrease in traffic bursts in 2 times approximately.

Exchange network and colocation network parameters

The network monitoring system within the exchange perimeter and within the colocation zone perimeter (including the colocation zone core switches) showed that the network parameters had no deviation from normal work parameters. No retransmissions, packet loss or network latency growth were detected.

We remind you that network bandwidth recommendations and requirements are published on MOEX website at <https://www.moex.com/a1160>.

Subsystem for real time monitoring of the trading system parameters and market activity

Monitoring for the maintenance divisions and technical support. The monitoring facilities have operated well and provided data visualization in graphic form during the load test. Message signals were produced in accordance with the established criteria; data was collected to the monitoring database without fails. Operation of the monitoring system did not influence the facility performance.

Corvil network monitoring system. During the tests, the Corvil (www.corvil.com) equipment and software, which had been adapted to analyze trading systems network traffic for all markets has been actively used. The network monitoring system operated correctly for Equities, FX, and Derivatives markets data.

Index server, market maker server, MOEX web site

All the listed systems have operated correctly, no failures or performance problems have been noted.

Test of clock synchronization over PTP (precision time protocol) at stress load

For each data center, an infrastructure for synchronizing system clocks over a high precision PTP protocol is deployed. During the tests, its stability at unusually high network loads on the Exchange infrastructure has been checked.

Precision checks for clocks on the network devices have shown that the time deviation has been no more than 500 nanoseconds and that is considered to be the excellent result. No failures of synchronization on the network devices or servers have been noted.

Conclusions

The Equity & Bond Market, the FX Market

1. Performance of the production Equities Market and FX Market systems is insufficient higher compared to values reached in 2020. The testing result appears to be good considering increased complexity of trading and clearing systems.
2. Components of the Equities Market and FX Market systems have been keeping acceptable technical parameters across the whole range of transaction frequencies. No failures of the system components caused by program errors or overload during this testing have been registered.
3. Clients are strongly recommended to use ASTS Bridge software version 4.3.7.1185 or higher that supports enlarged maximum size of requests to information responses.

Derivatives Market

1. SPECTRA's performance is sufficient to meet demands of participants even at peak loads with respect to order processing and market data distribution. Max processing rate is multiple times higher than peak loads detected for real trading (171,000 transactions per seconds during the tests vs 25,000 transactions per seconds during real trading).
2. We strongly recommend our clients to bring network bandwidth in line with requirements published at <https://www.moex.com/a1160>:
 - At least 15 Mbps is required for stable operation of client bridges/terminals per each software instance,
 - At least 20 Mbps is required for a bridge in case of using feeds with a full order/trade log (FORTS_ORDLOG_REPL/FORTS_DEALS_REPL).
3. The average RTT value has decreased from 100 microseconds to 75 microseconds within the range of real trading (from 3,000 to 30,000 transactions per second).
4. The average RTT value within the range of 30,000 – 65,000 transactions per second has increased by 14%, from 125 microseconds to 150 microseconds. Decline of performance parameters and latency is induced by the higher complexity of algorithms and peak frequencies emerging caused by implementing business cases with the releases of SPECTRA system in 2020.

Decline of performance parameters and latency near the peak load is induced by implementing new functionality on the business logic layer with releases of the SPECTRA system in 2020. When developing new functionality, the complexity of system engine algorithms has increased significantly.

5. During the test, we have detected problems with adapters for receiving data about orders and trades of Derivatives Market Backoffice and with capacity of virtualized servers Plaza2 for on-line market data under conditions of load level up to multiple times higher than the actual production. Changes to solve detected problems are planned.

Comparison of load test parameters and peak load values in real trading

Comparison table including result values reached during load test and peak load values detected in real trading are presented below. Configuration parameters for maximum number of orders and trades in the production environment of Equities, FX and Derivatives markets are also included. Configuration parameters can be increased by 2 or 3 times without the hardware upgrade.

Parameter	FX Market	Derivatives Market	Equities & Bonds Market
Detected peak load value, trades	300 000	3 371 091	3 000 000
Value reached in the load test, trades	2 878 998	12 253 444	4 220 823
Detected peak load value, orders	20 000 000	59 147 377	40 000 000
Value reached in the load test, orders	55 173 416	144 870 693	62 749 115
Maximum trades number, production environment	3 000 000	Inapplicable	6 000 000
Maximum orders number, production environment	100 000 000	Inapplicable	100 000 000
Peak transaction frequency detected in real trading	8 000	25 000	7 500
Peak transaction frequency reached in the load test	81 479	150 000	79 028