

THE BLUE STREAM PIPELINE INSPECTION PROJECT

AN OVERVIEW OF THE CHALLENGES FACED IN ORDER TO CLEAN AND INSPECT THE 24" x 380 KM PARALLEL NATURAL GAS INTERCONNECTOR PIPELINES BETWEEN RUSSIA AND TURKEY

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1. Project Introduction

Infrastructure Overview

The Blue Stream Pipelines are a transport system for the supply of gas from the network of southern Russia to Turkey through the Black Sea, with capacity to transport 16 Gm³/year. The asset consists of a number of gas pipelines totalling approximately 1,250 km, consisting of a 56" pipe, 373 km long across Russia, owned by Gazprom, from Stavropol to Dzhubga, two 24" pipelines across the Black Sea of 380Kms each, from Dzhubga to the Durusu station (Samsun); which is the Joint Venture between Gazprom & ENI (Blue Stream Pipeline Company- BSPC) and a 48", 470Km pipeline linking up with pipeline networks at Ankara, operated by Botas.

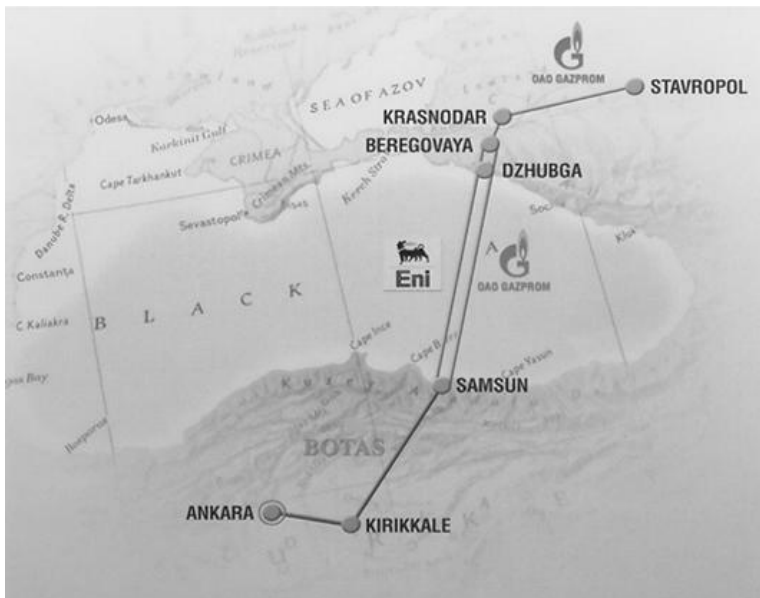


Figure 1- The Blue Stream Pipeline System

Blue Stream is undoubtedly one of the most challenging projects of its type ever attempted because of the difficulties in terms of design, construction, organisation and logistics. The significance of the operational performances on the Blue Stream system derives from the unprecedented difficulties of the two sea-lines. Geotechnical, geomorphologic and bathymetric characteristics of the seabed, to be traversed by the pipelines, presented varied and challenging features. Ultra deep water, H₂S environment, steepness of the slopes and geo-hazards, are the key design considerations that Saipem faced during design, installation engineering and construction. Courtesy of Blue Stream website www.bspc.com

The inspection challenge was that the two offshore pipelines were laid at a record depth of 2,150 m and run from the Russian shore to the Turkish side of the Black sea, effectively an interconnector pipeline between two continents.

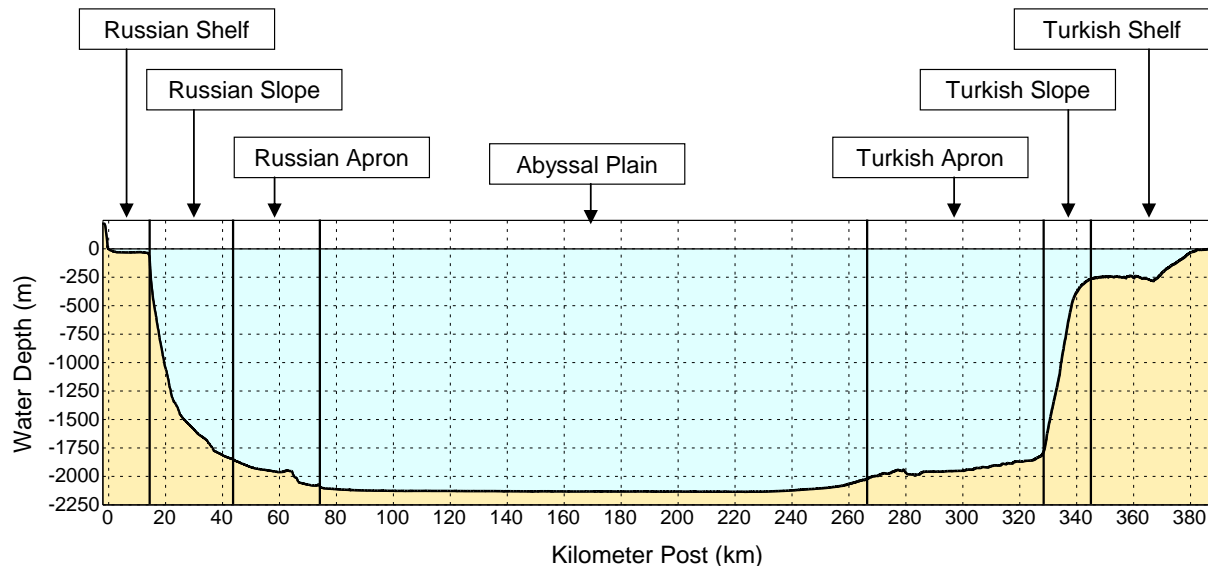


Figure 2 - Profile of the Black Sea along Blue Stream pipeline route, showing the 7 bathymetric provinces.

Project Requirements

- Pipeline Cleaning & Proving - to ensure the pipeline is in a clean enough condition to receive the subsequent inspection vehicles.
- Calliper – Detecting any dents or ovalities in the ‘as-laid’ pipelines.
- Out-of-Straightness Survey – to detect and measure the out-of-straightness or strain events in the as-laid conditions or and free spans.
- Magnetic Flux Leakage (MFL) High resolution Metal loss Survey – to inspect for any metal loss or corrosion.

Inspection Project Challenges

Below are listed the project challenges for the inspection tool design:

- Diameter: 24” with reduced bore tees – diameter 505mm (83% of Outside Diameter)
- Line lengths: 380 & 387 Km
- Depth max.: 2140m (7021’)
- Pressure: 250 bar (3625psi)
- Temperature: - 10C to +55C
- 7D bends
- 32mm wall thickness
- Ball Valves
- Barred tees
- Buckle arrestors
- Internal epoxy coating
- Flow ~ 2.5m/s

2. Project Approach

A feasibility study was done up-front in the project to review the pipeline and operational specific features and to identify the technical risks. The main challenges on the inspection system were identified as:-

- Wall Thickness requirement of 32mm
- Reduced bore passing – to cater for thick wall transition at the tee near the receive trap
- Pressure 250bar

The clients concerns for the tool running in the pipeline were:-

- **'NO STUCK TOOLS'** – The number 1 criteria was that any form of lodgement was unacceptable.
- Internal coating – the inspection tool must not damage the internal pipeline coating.
- Durability of the tool must last the 380Km+ range.

Engineering layouts and early magnetic analysis was done on the 24-30" MFL inspection to verify the bore passing and wall thickness capability. Technical and operational risks were identified, and a proposal produced, which outlined what needed to be done to convert the tool, and tests to be completed early in the main programme to improve the probability of success.

The feasibility study established that all of the challenges could be met using PII's 24-30" Multi Diameter Magnetic Flux Leakage Tool.

This proposal was accepted by BSPC and the PII team embarked upon the development changes to the 24-30" Multi Diameter MFL inspection tool to satisfy the specific requirements for this project.

The subsequent development phase concentrated on the following:-

- Engineering Design & Proof of Concept
- Sizing model generation
- Tool Design & Build
- Project Execution

3. Challenge Specifics

The BSPC pipeline was particularly challenging from a design and operational perspective due to the fact that it was 2140m deep in the Black Sea, gas at 250bar, thick wall pipe ~35mm & local full bore forged tee at Receive of 505mm diameter (i.e. 83% of nominal outside diameter). The following sections discusses the specific challenges faced and what was done to mitigate the associated risks.

CAD Simulation & Magnetic Modelling

One of the biggest challenges to the tool design was the saturation of the pipe wall with enough magnetic flux to conduct a successful inspection. 3D CAD modelling simulations were done to model the bore passing and feature passing requirements of the BSPC pipeline and at the same time check for magnetic saturation in the thick wall sections. The most severe geometry feature in the pipeline was the diameter 505mm (17% restriction) thick wall tee near to the receive site and the thick wall sections circa 32mm.

Buckle arrestor sections of pipe spool were integrated as part of the pipeline which was ~47mm thick. The client was not interested in inspection through these sections due to the excessive corrosion allowance built in. However PII were challenged to see what we could derive from inspections at the transition between the nominal pipe and the thick wall buckle arrestors.

Enhanced Flux handling techniques used to generate an articulated bar return path design that was superior in handling the magnetic field compared to conventional sweeps brush techniques. This was based on proven concepts previously used to increase the wall thickness capabilities on small diameter tools but not previously used on a segmented body tool. The tool was designed with the most powerful commercially available rare earth magnets in the maximum space volume to achieve the local full bore passing requirement of the thick wall tee.

The articulated return path design of magnetic vehicle was designed for a multi diameter application 24 to 30". For BSPC the requirement was for single diameter, so to maximise reliability the articulated mechanism for the return path bars was effectively locked down in the 24" mode, to allow the magnetic vehicle to behave like a fixed body.

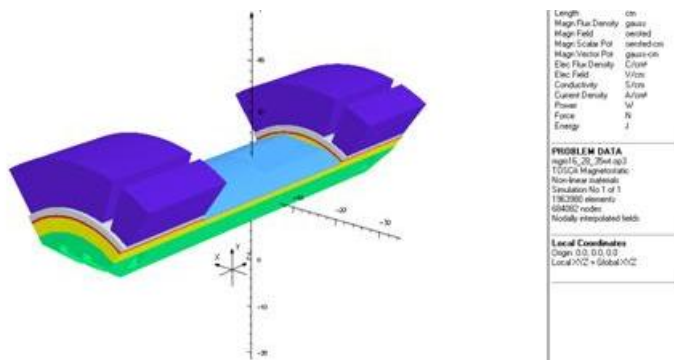


Figure 3- Magnetic modelling of the Flux intensifier return path bar

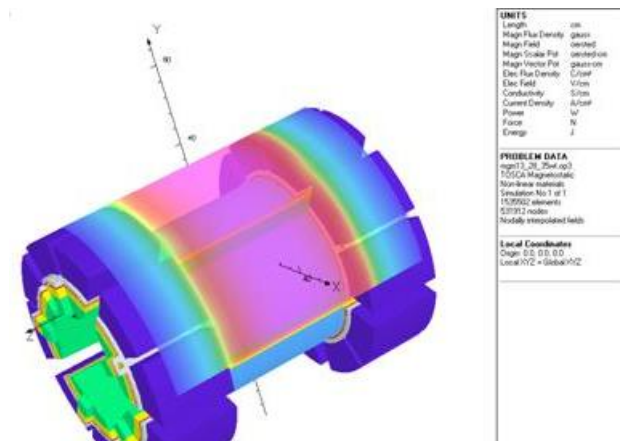


Figure 4- Magnetic modelling of the array of return path bars to check the uniformity of the field distribution between bars and along the axis between poles

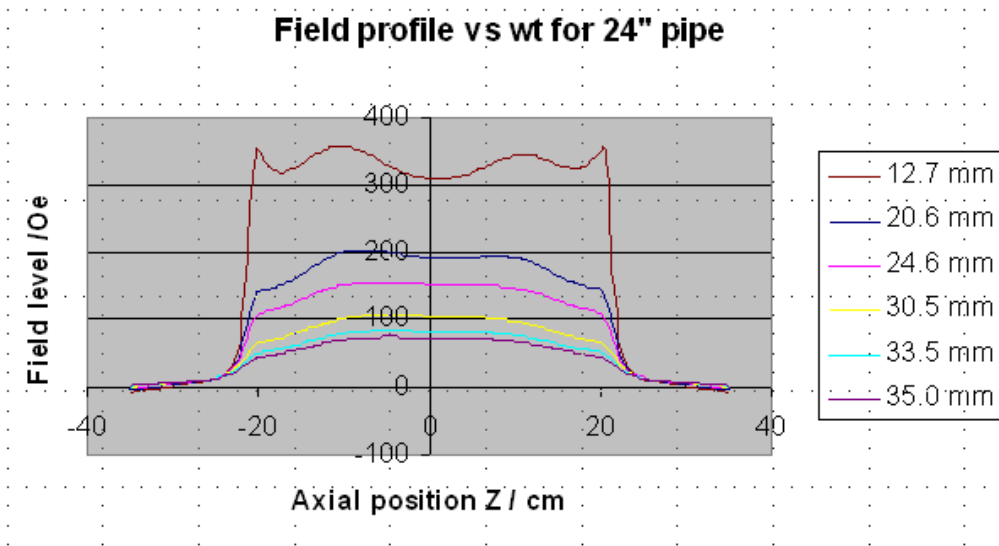


Figure 5- Predicted magnetic field levels

This graph shows the predicted magnetic field levels for the magnetiser arrangement in different wall thicknesses in the axial orientation. It is used to check the stability or flatness of the field levels relative to axial position. This is then used to determine the optimum position for the sensors. As can be seen from the above graph the field levels are relatively flat for the BSPC range of wall thickness allowing us some flexibility where the sensors can be positioned axially.

The analysis of the magnetic circuit predicted the following performance:-

Pipe Diameter	Predicted Min WT / mm (Inch)	BSPC Min WT / mm (Inch)	Predicted Max WT / mm (Inch)	BSPC Max WT / mm (Inch)
24Inch	13.70 (0.539)	25.4 (1.000)	38.10 (1.500)	32.0 (1.260)
* Pull Throughs required to verify top inspection speed for 32mm thickness inspection and static field measurements				

Table 1- Magnetic Circuit Performance

In summary, following all design and testing, the results demonstrated that the magnetic circuit was capable of inspecting 32mm WT at 2m/s minimum.

Pipeline Inspection Data Analysis Software & Pipeline Sentencing

Due to the high pressures exerted on the external surface of the pipeline, by both the water depth and the pressure of the gas inside the pipeline, the sentencing of the pipeline had to be carefully taken into consideration to ensure the actual forces were being calculated at any given depth. The data analysis software produced for the BSPC subsea network took into account the external collapse pressures as well as internal process forces dynamically and progressively for the entire length of the assets.

Pig Recovery Strategy

It was essential during the design and development of the tools that on no account should any tool become stuck in the pipeline and block production flows.

Most large size complex intelligent inspection systems are multi module to accommodate the magnetic module, front end processing data storage and power supply functions. It is therefore not recommended to push the tool from behind, as the tow couplings would tend to jack knife. This could

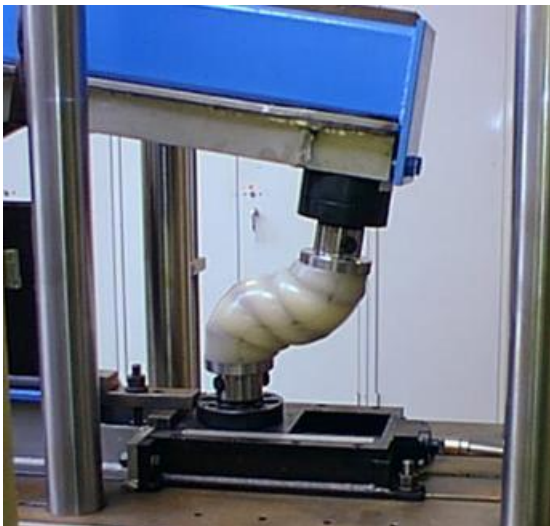
damage the tool to the extent that the rear most modules behind the magnetic vehicle become disconnected from the main inspection train.

PII had previously designed a 24-30" multi diameter thick wall inspection system for operation in liquid pipelines at depths of 7700ft that had to negotiate vertical asymmetric equal and unequal wyes. This experience was brought onto the BSPC project to ensure that the design of semi rigid tow bars could accommodate the various loading conditions imposed during normal pigging operations and at the same time be structurally sound enough to be able to be pushed from the rear.

Engineering layouts and simulations were done to ascertain the best combination of semi rigid tow coupling whilst connected to the adjacent vehicles. The designs were prototyped and tested to ensure satisfactory performance for:-

- **Tensile loading** – ability to pull the trailing modules through the pipeline
- **Compression loading** – ability to withstand the compressive loads generated when the high drag lead module suddenly slows down at a thick wall transition or bend and the inertia of the trailing modules tries to push it closer
- **Offset Strut loading** – ability to withstand the offset loads caused during negotiation of thick wall transitions or bends – as per compression loading case – but when the axis of the adjacent modules are offset – i.e. not in line
- **Bending loading** – ability to withstand the bending loading induced on the tow bar whilst negotiating bends
- **Torsion loading** – The trailing modules of MFL pigs are designed to induce rotation of the tool to ensure even wear and improve drive and sensor reliability. The tow bar assembly has to withstand the torsional loading to minimise the torsional misalignment between the main corrosion sensors and the positional recording system in the data acquisition pack, located in the trailing vehicle.

As can be determined from the above, the design of a semi-rigid tow coupling is not straight forward. PII designed several prototype units, manufactured the hardware and conducted a series of prototype tests that were necessary to hone in on the final design. Figures 6 and 7 show some of the tests that were done to validate the design.



Figures 6 & 7- Testing of Prototype Semi Rigid Tow Coupling

Once the tow bar design was finalised all that needed to be done was to fit a flat pushing facility at the rear of the train, to allow a recovery pig to push against.

As part of the system tests, PII successfully demonstrated that a recovery pig could be manoeuvred up behind the stationary inspection tool and push the whole arrangement along through the test rig. This arrangement was previously verified across a test rig which contained an asymmetric wye.

Location & Tracking

An electromagnetic transmitter was fitted to the tool as standard and magnetic sensitive timer boxes placed at strategic positions on the onshore pipeline sections so that in the event that the pig was stuck, there was a possibility of finding it. For the subsea piece of the pipeline, the transmitter could be detected by a suitable receive device fitted to an ROV, however the client insisted that the pig could be recovered by another pig - hence the emphasis on recovery strategy. Acoustic monitors were fitted at both Launch and Receive sites so that the pig position along the pipeline could be tracked and monitored

Pipeline Pressure 250bar

Standard MFL inspection systems in the PII fleet are certified for operation in both liquid and gas to 220bar. The 24-30" system used to inspect BSPC pipeline was tested and certified for 400bar operation in liquid pipelines only. The requirement for operation at pressures up to 250bar meant that we had to conduct design verification tests with the sensor hardware and external harnessing in compressible products up to 250bar. Tests were successfully passed.

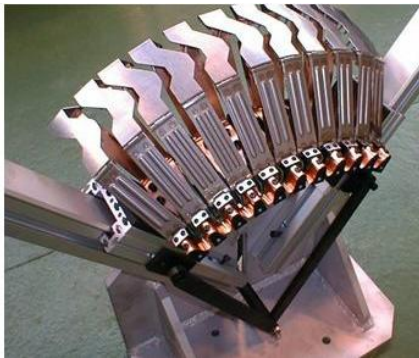


Figure 8- MFL sensor arrangement

Pipeline Cleaning



Figure 9- Cleaning Tool

The design of the cleaning tools had to be carefully considered. The removal of any dust or debris in the pipeline is crucial in obtaining a successful inspection; however, the abrasion was a factor for all pig runs and the protection of the integrity of the coating. Figure 9 shows the received cleaner, with minimal wear considering the pipeline length. The quantity of dust and debris was very small due to the quality of the gas and transportation process and the excellent construction of the pipeline.



Figure 10 -The MFL pig received in Turkey after 387Km run

4. Project summary

The two pipelines were successfully inspected and the results issued to BSPC. Figure 10 illustrates the safe receipt of the MFL tool following the 387Km run. The operation included the safe tracking of the pigs on both of the onshore sections acoustically and magnetically out of the traps and safely into the receive traps. Launching the tools in Russia and receiving in Turkey presented the team with customs and local certification challenges, including the requirement for local operating licences and permits to import and operate the tools in both countries, and to produce all documentation in both languages.

The overall design & operation was undertaken in a very cooperative and open spirit. The challenges and hurdles were surmounted at each design stage and all milestones presented and evaluated before moving to the next.

All of the pigs that were launched into the BSPC pipelines were safely received on time, and the rescue pig mobilised with the equipment was not required during operations. The calculated run time was 92 hours and the actual run times were within 15 minutes of the calculations. Credit must go to the SAIPEM team, who were technical consultants for the project for the computation of the run times.



Figure 11- Launch Site in Russia



Figure 12- Photograph of the two receive traps in Turkey

References

Massimo Volpini- Technical Manager- BSPC
Francesco Tommasi-Procurement Manager- BSPC
Claudio Mondo- Project Manager- SAIPEM Energy Services