1. BACKGROUND

1.1. The vendor introduction

Scientific Technical Center “SINTEZ” (hereinafter named as STC "SINTEZ") is a part of the Federal State Unitary Enterprise D.V. Efremov Scientific Research Institute of Electrophysical Apparatus (hereinafter named as Efremov Institute, http://www.niiefa.spb.su).

Director of the Efremov Institute – Dr. O.G. Filatov (filatov@sintez.niiefa.spb.su).

The administrative staff of Sintez are:

Director of SINTEZ Dr. Valery Belyakov (belyakov@sintez.niiefa.spb.su)
Deputy Director of SINTEZ on Economy Mr. Yuri Nekrylov (office@sintez.niiefa.spb.su)

STC "SINTEZ" possesses the rights of a separate legal entity in the domestic and international commercial contacts, whose activity is focused primary on the design, analysis, production and tests of complex installations for the controlled thermonuclear fusion; power supply and commutating equipment for the large scale electrophysical and electrotechnical devices; normal conducting, cryoresistive and superconducting magnet systems of various types and scale for physics research, thermonuclear devices, inductive energy storage systems for the pulse power supply of electrophysical installations and for the utility needs, etc. As a part of this activity STC "SINTEZ" collected a rich experience in the development of all kinds of quench protection (QP) and data acquisition systems (DAS).

Last years activity of the STC "SINTEZ" on superconducting magnet systems and their components, focused mostly on the participation in the International Thermonuclear Experimental Reactor (ITER) project, is briefly outlined in the attached papers “Activities on ITER Superconductors in Russia” and “ITER TF Conductor Insert (TFCI) Coil Manufacture”. TFCI was manufactured and tested at al experimental test facility of JAERI (Naka, Japan) in 2002. The main results is presented in attached paper “Test of the TFCI”.

The scope of the previous activity of the STC "SINTEZ" and the Efremov on SMES development is also concerned with superconducting magnet energy storages and high power superconducting switches.

1.2. Previous activity

In 1965 Efremov Institute had started a program on building superconducting
inductive energy storages, magnetic systems for tokamaks, accelerators and other electrophysical devices.

1.2.1. Large scale superconducting devices

The first large-scale superconducting solenoid with 1.2 m average diameter of turn was manufactured in 1969.

Over the period of 1970-1974 such equipment was designed and produced as:
- a superconducting quadrupole magnetic lens;
- a combined superconducting solenoid “KS-250” with a magnetic field induction of 25 T;
- superconducting DC transformers for the conductor sample power supply with test current of up to 80-100 kA.

In 1972-1975 the 30MJ, 6 T NbTi Solenoid HYPERON was developed and manufactured for the ITEF (Russia).

In 1978-1984 the prototypes of superconducting dipole magnets for 2000 GeV accelerating storage facility of the Institute of High Energy Physics, and for the “NUCLOTRON” accelerator facility of the Joint Institute for Nuclear Research were produced.

Over the period of 1977-1988 the set of 1 MJ-range experimental SMES units with bath and circulation cooling were developed and tested.

Since 1989 Efremov Institute developed a program of NMR tomograph application. In 1995 the pilot superconducting tomograph with 0.5 T, 10^-5 homogeneity magnetic field was manufactured.

In 1980-1988 the design and manufacturing was accomplished of a superconducting toroidal field systems for the largest Russian tokamak machine T-15 (magnetic field 8 T and stored energy of up to ~700 MJ).

Since 1988 Efremov Institute has been involved in the international project of the experimental fusion reactor ITER. The STC “SINTEZ” is the leader and coordinator of R&D work for ITER undertaken in Russia.

In 1999-2002 the design was accomplished of ~5 T superconducting LDX Charging Coil (Fig. 1.1.1) including the cryostat with warm bore ∅1300 mm. The tests of the coil will be started in Feb. 2003.
1.2.2. Medium and small-scale superconducting systems (magnets and cryostats)

Simultaneously with the above mentioned activity, a large number of superconducting systems with bath and circular cooling was designed and manufactured to resolve the scientific and technical issues of the large-scale projects and for other purposes. Some examples are shown below:

- The 8 T superconducting magnet (Fig. 1.2-1), the 5 T superconducting dipole magnet and the cryostat of 300 mm in diameter for AC losses test equipment (Fig. 1.2-2).
- The 5.5 T magnet system and cryostat for the experimental investigation of design material specimens. The main feature is warm hole $\varnothing 145$ mm.
- The 900 kN electromagnetic press with superconducting coils \([1, 2]\).
- The LIS-12 test equipment for high-current superconducting cables. It consists of a superconducting 12 T split solenoid, direct current transformer with secondary current 100 kA and cryostat $\varnothing 1$ m.
- The 7 T NbTi solenoid developed for “Quantum design” (USA) and used in research experiments is shown in Fig. 1.2-3.
- The HERMES Recoil Detector (HRD) magnet for DESY (Germany) is shown in Fig. 1.2-4.
Fig. 1.2-1. Superconducting 8 T solenoid and cryostat with ∅300 mm

Fig. 1.2-2. Superconducting 5T dipole magnet
Fig. 1.2-3. The 7 T solenoid with operating current 35 A.

Fig. 1.2-4. The 1 T HRD magnet with operating current 166 A and warm hole.
1.2.3. Another experience

In addition, the STC “SINTEZ” specializes on design and production of various components for superconducting magnet systems, e.g. high voltage current leads, insulation breaks, superconducting switches, etc.

As an examples the 35 kV 4 kA High-Voltage Current Leads (Fig. 1.2-4) can be mentioned just as up to 10 MPa in internal operating pressure High Voltage Electric Breaks for cold and warm helium (Fig.1.2-5).

Fig. 1.2-4. 35 kV 4 kA High-Voltage Current Leads.
1.3. Facilities

1.3.1. Engineering staff and facilities

The team for superconducting solenoid R&D and testing will be selected from the degree and PhD qualified engineers, research staff and CAD design draughtsmen of the following Departments of STC “SINTEZ”:

- Design Department
- Stress Analysis Department
- Magnet System Analysis Department
- Superconducting Magnet System Department
- QA Control Laboratory

The staff of the STC “SINTEZ” is trained in the international cooperative work during more than 10-year participation in the international projects like ITER and the works under the contracts with foreign firms and institutions.

The working language of the documentation, meetings, conferences and presentations will be English.

The following engineering facilities are available to the staff of STC ‘SINTEZ”:

- High power PCs linked into the LAN networks, including access to networked software packages for using of engineering and design databases
- Computer codes for text processing, computation and drawing preparation
- Information retrieval through on-line Internet databases
- Two-way traffic of documentation and drawings with Internet (E-mails and FTP-protocol).
- ISO 9001 Quality System

1.3.2. Computer codes

The following packages are proposed to be in use for the superconducting solenoid, cryostat and structure R&D:

A) Wording processors - Microsoft Office 97 for Windows 95 /NT 4.00 (licensed)

B) Packages for drawing preparation - ACAD-14 (licensed)

C) The codes for electromagnetic analysis
The last codes are based on the techniques and approaches originally developed by the staff of the STC “SINTEZ”, verified with the problems allowing analytical solutions, and have been already used and tested in the long-term practice on the design of numerous installations produced by the STC “SINTEZ”:

· Codes for 3D FE analysis of the magnetic/electrostatic fields and transport current distribution (KOMPOT package)

The KOMPOT package numerical simulation algorithm is based on the magnetic scalar potential conception, the finite element method and the symmetric successive over relaxation method combined with a polynomial acceleration of the convergence rate. The KOMPOT results have been successfully used in designed magnets for accelerators, fusion and MHD-generator magnets, spectrometer and MRI-magnets (such projects as SSDL SDC Detector, USA; HERA electron-proton collider at DESY, Germany; T-10, T-15 tokamak devices, Russia and so on)

· Codes for the eddy currents, forces and AC losses computation for the rods, vessels and structure (TYPHOON package)

The problem of transient electromagnetic analysis is solved by 3-D final element method. A standard test problems developed at Testing Electromagnetic Analysis Method (TEAM) Workshops were used to verify the code. TYPHOON code was used during design of ITER (computation of electromagnetic loads on vacuum vessel, blanket, divertor and surrounding conduction structures; AC losses in ITER mechanical structures), TEXTOR tokamak in KFA/IPP, Germany and NMR tomograph in Efremov Institute, Russia.

· Codes to evaluate the induced currents (coupling and supercoupling) and AC losses in superconducting strands and cables, taking account of the transport current and saturation effects (PLRMFC, PLRTCS, HITRAN, ASTRA codes)

Some techniques (and corresponding codes) to compute AC losses in the multistage cables, to analyze coupling-current behavior of superconducting cables of finite length, to take into account the additional self-field activated circulation currents were developed during ITER engineering design activity.

D) The codes for the thermohydraulic analysis

Steady state and transient thermal analysis of the superconducting solenoid will be performed with the COND and VINCENTA codes developed by the staff of the STC “SINTEZ” to support the design of superconducting magnet systems. The codes are multipurpose and intended for:
- Simulation of the cool down/warming-up of superconducting windings
- Normal zone propagation and quench analysis for the superconducting windings under a quasi 3-D approximation
- Steady state and transient analysis of superconductors (normal operation, quench, stability analysis)
- Simulation of a cryogenic system (including multichannel piping, current leads, valves, etc.) response to the transients in the superconducting windings
- Cryogenic current lead steady state and transient analysis

The codes COND and VINCENTA are well known to, and have got approval of, the international scientific community involved into the ITER project.

E) Stress analysis codes:

- ANSYS 5.3 codes (licensed)
- MARINA FE codes developed by the staff of STC “SINTEZ” (15 years of evolution)
- FEA FE codes developed at the St. Petersburg Technical University (21 years)

Two last codes show good correlation with the results obtained with using of well-known codes as ANSYS, NASTRAN and so on for the similar problems.

1.3.3. Workshops

The following workshops are proposed to be in use for the superconducting solenoid, cryostat and structure manufacturing:

A) Factory of electrophysical equipment “EFO”.

This Efremov Institute division is now a multipurpose production one with experienced managers, engineers and workers. The machining welding, vacuum annealing, electroplating, winding and etc. shops allow to produce and QA control of the both electrophysical large-scale (accelerators, tokamak-reactors, 6 m in length dipole magnets, stellarators, etc.) and medium- small scale (magnets, cryostats, current leads etc.) devices.

B) The STC “SINTEZ” winding equipment

The STC “SINTEZ” has special equipment and staff for winding (Fig. 1.3-1). Automated machines allow to control the rate (turns in min) and the pull (N) of winding.
Fig. 1.3-1. A specimens of winding equipment for (a) small- and (b) large-scale coils.

C) Vacuum pressure impregnation (VPI) shop
The equipment of Efremov institute division allows to impregnate both large- (Fig. 1.3-2) and small-scale coils.

Fig. 1.3-2. The VIP equipment for large-scale winding.

D) TIG or industrial CO₂ lasers equipment
This equipment of Efremov Institute division is available for the welding of composite copper/stainless steel parts of cryogenic devices.

E) QA control of welding will be performed with the available He leakage, due penetrate, X-ray and ultrasonic techniques by STC “SINTEZ” equipment

1.3.4. Test facilities
The available Cryogenic Test Facility of the Superconducting Magnet System Department of the STC "SINTEZ" is intended and equipped for:
- acceptance tests of superconducting magnets or their parts with cold mass of up to 5-10 tons
- research for development/optimization, certification and acceptance tests of superconducting strands and cables (critical current, AC-loss and stability measurements) in the background magnetic field of up to 12 T and with a transport current of up to 80 kA
- research for development and acceptance test of the components of superconducting magnets (current leads, joints, superconducting switches)
- research for development and tests of electrical insulation of superconducting magnets (up to 135 kV DC and 270 kV AC, LHe or "cold" vacuum electric testing with or without mechanical loading of the samples with the force of up to 900 kN)
- research for development and tests of the instrumentation of superconducting magnets (voltage taps; thermometers; Hall probes; strain gauges; quench detection systems including ones basing on the Super High Frequency, Optic Fiber and AE sensors; floating or magnet levitation gas flow meters, etc.)

The facility (Fig. 1.3-3) with the experimentation area of 500 m² is equipped with:
- Two He liquefies/refrigerators of KGU-150 type each capable to produce of 20 liters of LHe per hour and to provide He flow with the rate of up to 9-17 g/s at 0.13-0.5 MPa, 4.5-5.5 K inlet temperature.
- Programmable DC power supplies:
  - IST-5000 (2 units) for 5 kA, 60 V
  - IST-10000 (1 unit) for 10 kA, 24 V
  - VAKG (1 unit) for 1.5 kA, 24 V (or 3.2 kA, 12 V)
  - IST-1600 (1 unit) 1.6 kA, 90 V
  - and others
- Superconducting DC transformers for the secondary circuit currents of up to 80-100 kA
- Test cryostats with 300, 560 and 1000 mm diameters of He vessels (two units of each type)
- High Voltage Test Station of GBS-14/135 type, produced by TUR
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Superconducting DC transformers for the secondary circuit currents of up to 80-100 kA

Test cryostats with 300, 560 and 1000 mm diameters of He vessels (two units of each type)

High Voltage Test Station of GBS-14/135 type, produced by TUR

Data Acquisition System (DAS) with the schematic shown in Fig. 1.3-3, featured with:
- Analog devices for magnetization measurements of losses
- Floating ball and magnet levitation gas flow-meters for calorimeter measurement of AC loss
- Analog devices for the calibration of low-temperature sensors
- Hardware of “National Instrument” (amplifiers, analog-digital converters)
- Industrial computer (2) produced by “Advatech”

• Complex set-ups:
  - LIS-12 set-up for the critical current measurements for the short samples of superconducting wires and cables (90 x 25 mm in cross-section) in the DC background field of up to 12 T at test current of up to 60-80 kA from the DC transformer. The set-up was initially designed for testing the samples of Nb3Sn superconductors of T-15 tokamak-machine.
  - AC loss measurements station based on the 1 m in length 5 T superconducting dipole.

The main feature is a possibility to test the conductor and strand specimens simultaneously with magnetization loop and boil-of calorimetric technique. Magnetic field pulses are transverse and parallel (3.5 T amplitude, 0.5 T/s sweep rates without normal transition of the pulse test coils; up to 5 T amplitude, 2-3 T/s sweep rate in a single-pulse test with the normal transition of the test magnet). The stations were initially developed for testing of the ITER Cable-in-Conduit-Conductor (CICC) full-scale samples.
- The set-up for CICC sample stability measurements, consisting of:
  * the 5 T background field DC solenoid
  * System of the pulse test coils generating up to 2 T parallel field and up to 0.5 T perpendicular field
  * Racetrack bifilar wound CICC sample (15 mm dia of CICC; 15-20 m length of CICC)
  * Inductive and Ohmic heaters generating the test disturbance pulses

- The set-up for low-temperature high-voltage electric tests of the samples of electrical insulation in LHe or "cold" vacuum under the voltage of up to 135 kV DC and 270 kV AC presence of the magnetic field (stray field of superconducting solenoids of the magnetic press) and the mechanical load of up to 900 kN.

1.3.5. Superconducting solenoid test facility

The superconducting solenoid tests are to be performed at the complex set-up to be combined from the following already available components:
  * Cryostat - 560 mm in dia, 1200 mm in depth or 1000 mm in dia, 2000 mm in depth multipurpose test cryostat
  * LHe/GHe supply - LHe in tanks and 9 g/s, 0.13-0.5 MPa, 4.5-5.5 K cryogenic line
  * Power supply - 10 kA, 48 V DC supply with 500 V protection circuit breaker
  * High voltage generator - High voltage test station of GBS-14/135 type
  * Flow meters, sensors, DAS - already available components of the Cryogenic Test Facility.

2. A list of foreign firms-customers of STC “SINTEZ” for previous 6 years

USA
  * MIT (Boston)
    BWXT (Lynchburg)
  * Sandia National Laboratories
  * Lockheed Martin Energy Systems, Inc
  * ISM Technologies, Inc (San Diego)
  * McDonnell Douglas Aerospace (St. Louis)

GERMANY
  * Forschungszentrum Julich GmbH Institut fur Plasmaphysik
  * Forschungszentrum Rossendorf C.V. (FZR)
  * Max-Planck Institut fur Plasmaphysik
  * Forschungszentrum Karlsruhe (EKM)
  * Deutsches Elektronen - Synchrotron DESY
  * Klockner Moeller GmbH
FRANCE
  · High Magnetic Field Laboratory (Grenoble)
  · Centre National de la Recherche Scientifique

JAPAN
  · Nisso Iwai Aerospace Corporation
  · Marubeni Utility Services, Ltd

UK
  · UKAEA (United Kingdom Atomic Energy Authority)

ITALY
  · ENEA Per Le Nuove Tecnologie L’Energia e L’Ambiente

ISRAEL
  · Nuclear Research Center (SOREQ)

AUSTRALIA
  · CSIRO Division of Telecommunication and Industrial
  · Physics National Measurement Laboratory