Progress of Nondestructive Testing and Evaluation in China

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Abstract: NDT&E plays a very important role on our daily production and during the industrialization in China. This paper reviews the history, personnel qualification and certification system, conference and instrument exhibition, standard, instrument, education, main research and application areas for NDT in China. China not only has a large requirement for conventional NDT instrument and materials, but also for advanced instrument, technique and service. China is being a big market for NDT instrument, technique and service.

Keywords: Progress, Review, Nondestructive Testing, NDT, China

1. Historical Background

The People's Republic of China was founded in 1949. Many large industrial projects such as power station, metallurgy, automation, mechanical manufacture etc had been constructed since 1950. The NDT technique and methods including in radiography test, ultrasonic test, magnetic particle test and dye penetration test were introduced into China from former the Soviet Union and western industrial developed countries in 1954[1]. These four kinds of NDT methods have been widely used since then.

In 1957, the first ultrasonic flaw detector was developed in China[2]. The automatic ultrasonic testing system for tube was developed in 1964. The birth of the first digital ultrasonic flaw detector was in 1988[3].

In 1958, China started to produce industrial X-ray film. The first moveable Co^{60} gamma ray machine was developed in 1960. The first X-ray apparatus was developed in 1964. The first X-ray real time imaging system was developed in 1991. The first gamma ray CT was developed in 1993. The first industrial X-ray accelerator and first Compton diffraction imaging system was developed in 1995[4].

In 1958, the first portable magnetic particle testing equipment was developed in China[5]. The color contrast penetrant was developed in 1962.

In 1960, the eddy current testing technique was introduced into China. The first eddy current instrument was developed in 1962. This method was gradually applied and disseminated in 1960s. The first digital, varied frequencies and multi-channel eddy current instrument was developed in 1993[6]. The first metal magnetic memory testing instrument was developed in 2000. The magnetic flux leakage testing equipment for steel piping and

plate was developed in 2002. The special eddy current testing instrument for surface crack of steel weld was developed in 2002.

In 1969, the acoustic emission testing technique was introduced into China. The single channel and six channels acoustic emission instruments were developed in the middle of 1970s. The 36 channels acoustic emission instrument was developed in 1986. This method was widely applied to aerial equipment, space equipment and pressure vessels testing in the second half of 1980s[7]. The first multi-channel acoustic emission instrument based on PC/AT bus and Windows software was developed in 1996. The first digital multi-channel acoustic emission instrument based on acoustic emission signal wave acquisition was developed in 1998[8].

In 1978, the Chinese Society for Non-destructive Testing (ChsNDT) was founded in Shanghai. At present, there are 26 local sub-societies for NDT and more than 30,000 members in China[9].

In 1970s, the infrared thermography technique was introduced into China[10]. The first infrared thermographic instrument was developed in 1978[11]. It has been used in power industry and petrochemical industry.

2. NDT Training, Personnel and Qualification System[12]

ChsNDT and 8 different governmental or industrial sectors individually carry out training, qualification and certification for NDT personnel in China. Total 8700 level III certificates and 255,400 level I&II certificates issued by them are valid now.

ChsNDT qualify and certify the NDT personnel according to ISO9712-2005 standard. The examination center of ChsNDT is responsible for qualification of level III personnel. The examination centers of local sub-society for NDT are responsible for qualification of level I and level II personnel. The secretariat of ChsNDT is responsible for preparation of the certificate for all level. The examination and qualification of four methods including RT, UT, MT and PT have been carried out. 43,000 certificates including in 3,000 level III certificates have been issued.

There are 8 governmental or industrial sectors to carry out training, qualification and certification for NDT personnel for different kind of industrial equipment and products according to their regulations in China. The details are shown as the table 1.

Table 1 Statistic of NDT Personnel for Governmental or Industrial Sectors

Governmental or industrial sectors	Testing Object	NDT Methods	Numbers of issued certificates
General Administration	Special equipment including	UT, RT, MT, PT,	Level III: 4026

of Quality Supervision, Inspection and Quarantine	in boiler, pressure vessel, pressure piping, elevator, crane, cableways and amusement rides.	ET, AE, TIR	Level I&II: 125,610
The Ministry of Railway	Locomotive, train and railway	UT, RT, MT, PT, ET.	Level III: 400 Level I&II: 62,000
Ministry of Industry and Information Technology	Aeronautical facilities, space equipment and weapons	UT, RT, MT, PT, ET, AE, LT, VT, CT, HS.	Level III: 150 Level I&II: 5,850
Ministry of Environmental Protection	Nuclear industrial equipment	UT, RT, MT, PT, ET, VT, LT.	Level III: 161 Level I&II: 5,729
The Ministry of Water Resources	Water Conservancy and hydroelectric equipment	UT, RT, MT, PT.	Level III: 90 Level I&II: 1,250
General Administration of Civil Aviation	Civil aviation equipment	UT, RT, MT, PT, ET.	Level III: 67 Level I&II: 918
Mechanical Industry (ChsNDT)	General machine	UT, RT, MT, PT.	Level III: 3000 Level I&II: 40,000
Electric Industry	Power station	UT, RT, MT, PT, ET.	Level III: 700 Level I&II: 5,600
Shipping Industry	Ships	UT, RT, MT, PT.	Level III: 110 Level I&II: 8,390

3. Conference, Symposium and NDT Instrument Exhibition

ChsNDT, her 6 technical committees and 26 local societies separately hold the conference and symposium for NDT in China.

ChsNDT is responsible for holding the nationwide conference and equipment exhibition for NDT every three or four years. 8 times of conference and equipment exhibition had been held since 1978. The last one was held in Suzhou city in September 2003. The proceedings collected 429 papers. 500 delegates attended the conference. There were 25 foreign delegates from Russia, Canada, Japan, India and UK. 82 NDT equipment and instrument companies attended the exhibition in this conference.

6 technical committees are radiography test committee, ultrasonic test committee, surface test (MT and PT) committee, electromagnetic test committee, acoustic emission test committee and non-conventional test committee. These committees organised special technology symposium every 2 years nationwide. The number of the delegates is usually between 60 and 150.

Local societies are responsible for holding local conference and equipment exhibition for NDT every four years. The number of the delegates is usually between 100 and 300.

The international quality control technique and testing instrument exhibition has been held in Shanghai in autumn every year since 1995. Each exhibition lasts for 3 days. More than 100 companies world-wide attend the exhibition. More than 10,000 people visit the exhibition. In addition, there are some irregular exhibitions for NDT equipment and instrument in big cities such as Beijing, Guangzhou, Tianjin, Shenyang and Chengdu.

4. NDT Standard[13]

Chinese national standardization technical committee for NDT (SAC/TC56) is responsible for the drafting of general standards for NDT. The NDT standards of industrial products are separately drafted by different kinds of products standardization technical committees. The secretariat of SAC/TC56 is in Shanghai research institute of materials. There are 51 members and 10 working groups in this committee. These working groups are AEWG, ETWG, LTWG, RTWG, TIRWG, UTWG, Surface Test WG, NDT Personnel WG, ISO/TC135WG and ASTME07WG.

Total 47 general national standards for NDT have been drafted by SAC/TC56 and approved by Chinese national standardization committee. Those standards include one standard for qualification and certification of NDT personnel, one standard for general rule of NDT, 10 terminology standards for general terms and definitions, radiography test, ultrasonic test, magnetic particle test, dye penetration test, eddy current test, acoustic emission test, neutron radiation test, infrared thermography test and leakage test, 11 testing methods and equipment standards for radiography test, 8 testing methods and equipment standards for ultrasonic test, 11 testing methods and equipment standards for surface test, 2 testing methods for acoustic emission sensors, 1 standards for leakage test, 1 standards for metallographic test. In addition, 30 methods and equipment standards of NDT of mechanical industry have been drafted by SAC/TC56 and approved by National Development and Reform Commission of China. Recently, SAC/TC56 drafts or revises about 10 standards every year.

In addition, 91 national NDT standards and 314 industrial NDT standards for different products have been drafted by many other product standardization technical committees and approved by different governmental sectors. Table 2 lists the details.

Table 2 Statistic of NDT Standards in China

Serial No.	Code	Sectors	Number
1	GB	National standard	138
2	GJB	National military standard	26
3	CB	Shipping industry	14
4	DL	Power industry	17
5	EJ	Nuclear industry	26
6	HB	Aviation industry	42
7	HG	Chemical industry	2
8	JB	Mechanical industry	110
9	JG	Construction industry	2
10	MH	Civil aviation industry	6
11	MT	Coal industry	2
12	QB	Light industry	2
13	QJ	Space industry	31
14	SY	Oil and natural gas industry	20
15	TB	Railway industry	33
16	YB	Metallurgy industry	11

5. NDT Instrument

5.1 The situation of market for NDT instrument in China

According to the non-complete statistic, NDT instruments valued more than 130 million US dollars were sold in China in 2007. Total 40% were imported from oversea. Table 3 lists the details.

Table 3 Statistic of Sale for NDT Equipment in China

Serial No.	NDT Equipment	Number of Sales	Value (Million US$)
1	AE	1,500 Channels	3
2	ET	500	20
3	MT	10,000	7
4	PT	/	10
5	RT	4,300	62
6	UT	3,000	18
7	Advanced technique equipment such as guide wave, infrared camera, pulsed eddy current test, laser, etc.	60	15

5.2 The situation of domestic producers for NDT instrument in China

At present, China has instrument and materials manufacturers for UT, RT, MT, PT, ET and AE.

There are 10 main manufacturers for ultrasonic flaw detection systems and 5 main manufacturers for ultrasonic transducers. All the products of ultrasonic flaw detector are digital. But no manufacturer can produce commercial phase array ultrasonic inspection systems. In addition, there is one company that can make EMAT instrument. There is one company that can make ultrasonic TOFD test instrument. There are 8 main manufacturers of ultrasonic thickness gauges.

There are 25 main manufacturers for X-ray machine, 4 main manufacturers for γ ray machines, 2 manufacturers of γ ray source, 2 manufacturers of industrial X-ray accelerator , 2 manufacturers for radiographic film and 4 manufacturers of digital radiographic imaging system. But the imaging cells of CCD and CMOS need to be imported from other countries.

There are 13 main manufacturers of magnetic particle testing instrument and equipment. These manufacturers can make both large stationary magnetic particle testing equipment and portable magnetic flaw detection. There are 5 main manufacturers for penetrant inspection. These manufacturers can make both general and nuclear class penetrant.

There are 10 main manufacturers for electromagnetic testing instrument and eddy current flaw detection systems. Their main products are digital multi-channel eddy current flaw detector with multi-frequency, remote field eddy current flaw detection, magnetic flux leakage testing instrument and metal magnetic memory testing instrument.

There are 2 main manufacturers for acoustic emission testing instrument. At present, the main product is digital multi-channel (2 to 128) acoustic emission instrument with acquisition of waveform signal for each channel.

5.3 The situation of foreign companies for NDT instrument in China

At present, the main manufacturers of NDT instrument and materials from the world have office, agency, representative or distributor in China. These companies are mainly from USA, Germany, Japan, UK, Canada, Russia, Italy, France, Belgium, South Korea and Israel. Most of their offices or agencies are in Shanghai and Beijing in China.

The larger count of main imported instrument and materials are X-ray machine, radiographic film, ultrasonic flaw detector, ultrasonic thickness gauge, portable magnetic flaw detector, eddy current flaw detector and acoustic emission testing instrument. In addition, the requirement is very strong for advanced and new technical instrument such as

real-time radiographic imaging system, phased array ultrasonic flaw detector, ultrasonic TOFD test equipment, C-scan ultrasonic flaw detector, ultrasonic guide wave testing instrument, MFL testing instrument for oil tank floor, metal magnetic memory testing instrument, and so on.

6. Education for NDT

At present, 18 universities and 6 junior colleges are being engaged in education of non-destructive testing and evaluation in China. Approximate 340 junior college students, 400 bachelors, 140 masters and 40 doctors graduate from these universities and junior colleges each year. Table 4 lists the statistic of graduated students for NDT. In addition, about 10 institutes from Chinese Academy of Science, mechanical industry, aviation and space industry recruit 60 postgraduates and 20 doctoral postgraduates each year. Nanchang Hangkong University, Beijing Jiotong University and Wuhan University are the main universities educating bachelors and masters of NDT major. Tsinghua University, Chongqing University, Beihang University and Huazhong University of Science and Technology are the main universities educating masters and doctors of NDT major.

Table 4 Statistic of Graduated Students for NDT in China Each Year

	Junior college student	Bachelor	Master	Doctor
No. of colleges or universities	6	6	18	11
No. of students	340	400	140	40

7. The main research and application areas for NDT in China[14]

7.1 The main research and application areas for RT[15]

The main research areas for RT including in automatic recognition of defect, computed radiography, real-time imaging of RT and computed tomography (CT) techniques.

Lanzhou Sanlei Corporation, Beijing Automatic Institute of Machinery and China Special Equipment Inspection Institute have developed RT real-time imaging system. These systems have been applied to weld testing of steel pipe and cylinders in many manufacturers. Tsinghua University has developed RT real-time imaging system for container. This kind of systems has been widely used in customs.

Chinese Academy of Sciences, Chongqing University and Northeast University have developed γ -ray CT instrument. Some industrial X-ray CT instruments and high energy (2～9MeV) X-ray CT instruments have been developed. These CT instruments have been applied to defect testing, size testing

and structure analysis for exact casting and welding parts.

7.2 The main research and application areas for UT[3,16-18]

The main research areas for UT are development of digital ultrasonic flaw detector, automatic ultrasonic testing, artificial intelligence, ultrasonic imaging, TOFD, ultrasonic guided wave testing technique and so on.

The first digital ultrasonic flaw detector was developed by Wuhan Zhongke Innovation Technology Company in 1988. Now more than 10 companies can produce digital carry-home and multi-channel ultrasonic flaw detectors. The maximum channels are 128 and the maximum sampling frequency is 100MHz for multi-channel ultrasonic flaw detectors. These multi-channel ultrasonic flaw detection systems are mainly used on automatic ultrasonic testing systems such as seamless piping, welding piping, wheels of train, drilling stem in oil field and key parts of automobile.

The research and application fields of TOFD technique include equipment developing, TOFD signals analysis and processing, boiler and pressure vessel fabrication test, pressure pipeline installation test and hydropower station equipment test in China. More than 10 boiler and pressure vessel manufacturers have bought TOFD ultrasonic testing equipment to take test for their products during fabrication. More than 5 inspection agencies have offered TOFD ultrasonic testing service. In 2005, Wuhan Zhongke Innovation Company developed one commercial TOFD ultrasonic testing instrument with HS800 as the model number in China. Wuhan Zhongke Innovation Company and CSEI are jointly developing new generation TOFD ultrasonic testing equipment. This new equipment can test welds of 6mm<wall thickness≤ 400mm with multi-channel.

China Special Equipment Inspection Institute (CSEI) is the only one national inspection and research organization for pressure equipment in China. CSEI used TOFD ultrasonic testing instrument itself developed to test several hundreds repairing welds for the natural gas pipeline from northwest to east of China in 2003. Since 2007, CSEI have used Omniscan MX of RD Tech, Isonic 2005 of Sonotron NDT and HS800 of Wuhan Zhongke to perform TOFD ultrasonic test for total 36 reactors and heat exchangers, 22 spherical storage tanks with 400 ~ 3,000m^3 volume and 14 oil storage tanks with 100,000m^3 volume. The thicknesses of these pressure vessels and storage tanks are between 28mm and 340mm.

More than 10 sets of ultrasonic guided wave testing instruments have been imported from TWI, Guided Waves Company and Southwest Research Institute recent years. These instruments are used in investigation and testing of corrosion for industrial piping with insulation and underground pipeline. CSEI has successfully applied Teletest guided wave

instrument to test 5 industrial piping with insulation and 27 underground pipeline since 2004. A lot of serious corrosion defects were found.

7.3 The main research and application areas for ET[6]

The main research areas of ET are eddy current testing, remote eddy testing, pulsed eddy current testing, magnetic flux leakage testing (MFL) and metal magnetic memory testing (MMMT) techniques.

The eddy current testing instrument has developed five generations from modeling to digital instrument. The recent instruments use many advanced electronic techniques such as DSP, array, multi-channel, signal transmission and analysis. Eddy current testing is widely used in on-line testing of tube in manufacturers and periodic testing of heat exchangers in power and petrochemical plant. Remote eddy current has been developed and used for oil industry by the Nanjing University of Aeronautics and Astronautics [29] and it is integrated with other modality of NDT & E such as pulsed eddy current [30] through international research collaboration. In 2005, China Special Equipment Inspection and Research Center (CSEI) imported a pulsed eddy testing instrument named INCOTEST from RTD in the Netherland. CSEI has successfully applied INCOTEST to carry out the investigation and application of corrosion testing of pressure vessel and piping with insulation.

The research and application of MFL include in bottom corrosion testing of oil storage tank, on-line testing of tube and pipe during manufacture, testing of steel rope, testing of drill stem in oil field and corrosion testing of industrial piping without insulation. Some inspection companies have imported FLOORMAP 2000 for bottom corrosion testing of oil tank and PIPESCAN for testing of industrial piping without insulation. The Huazhong University of Science and Technology has developed MFL instruments for oil tank, steel rope and drill stem in oil field. The MFL instrument for steel rope and drill stem has been diffusely used in all the big oil fields in China. The first MFL testing standard for storage tank, JB/T17065-2007 non-destructive testing — magnetic flux leakage testing of atmospheric pressure metal storage tanks, had been drafted by CSEI and approved by National Development and Reform Commission of China in 2007.

MMMT technique was raised by Doubov of Russia in 1990 and was introduced to China in 1997[19]. Now MMMT has been extensively used in many kinds of steel structure testing such as boiler tube and fillet, pressure vessel, pressure piping, aircraft, turbine and bridge in China[6, 20] . The first MMMT instrument was developed by Eddysun Electric Corporation in 2000. Tsinghua University and CSEI have also developed these kinds of instruments recent years.

7.4 The main research and application areas for AE[8]

Acoustic emission (AE) technique (AET) was introduced into China at the end of 1960s. AET has been widely used in metals, composites, metallic structures, pressure vessels, aircraft structures, concrete, rock, magnetoacoustic emission, manufacturing process monitoring and so on since then. More than 100 institutes, universities, colleges, inspection companies and more than 300 people are engaged in acoustic emission research and application in China. There are about more than 60 sets of 32 channels AE instruments, more than 200 sets of under 32 channels AE instruments in China. 70 percent of multi-channel (over 8) AE instruments and 30 percent of a few channels AE instruments was imported from USA and Germany[21].

The employed methods for AE Signals Analysis and processing include normal AE parameters analysis, time's difference AE source location, correlation figure analysis, modern spectrum analysis, pattern recognition analysis, artificial neural network pattern recognition, wavelet analysis, fuzzy analysis and grey correlation analysis.

The most important activities in AE testing in China have run to the scope of pressure vessel safety research and evaluation since 1980. Now more than 50 companies are engaged in pressure vessel testing with AE. Most of the multi-channel AE instruments are used for pressure vessel testing. More than 500 large size pressure vessels are tested every year. CSEI is the largest inspection company for pressure vessels[22].

The second successful application field is aircraft structures. In this field, AE is applied to monitor the production and growth of fatigue crack in aircraft structure. The work has been done by the Beijing Institute of Aeronautical Materials since 1983. A group led by Dr. R.S.Geng, The First Research Institute of the Airforce, has performed a lot of AE test for the fatigue test of airplane[23]. They passed through to introduce some new AE parameters based on the normal AE parameters to discriminate fatigue cracking signals in a bulkhead bolt from a number of friction noise signals.

Magnetoacoustic emission (MAE) for ferromagnetic materials has been investigated since 1984 in China. After studying the magnetoacoustic emission characteristics of grain oriented Fe-Si alloy, G.T.Shen and Y.H.Xu found that the motion of 180^{O} magnetic domain walls can generate acoustic emission signals[24,25]. The MAE and Barkhausen noise of Ni and carbon steel has also been studied[26-30].

7.5 The main research and application areas for Thermal/Infrared Test

Thermal/Infrared testing (TIR) technique was introduced into China in 1970s. TIR has been used in high temperature pressure vessel and pressure piping testing on-line. It also has been applied to testing of fatigue damage for normal temperature pressure vessel and cylinder in recent years in China[31,32].

Infrared thermal wave test technique and lock-in image technique was introduced into China in 2003. These technique have been applied to test the material and component of

aeronautic and astronautic equipment[33].

8 Conclusion

(1) At present, there are more than 170, 000 qualified NDT personnel and 2,000 NDT organizations in China. A lot of NDT instrument and equipment valued more than 130 million US dollars revenue were sold in 2007. Near 1,000 students of NDT major are graduated from college or University. China is being a big market for NDT service, instrument and technique.

(2) There are many NDT equipment and instrument manufacturers. They can make conventional radiographic flaw detector, ultrasonic flaw detector, ultrasonic thickness gauge, stationary magnetic particle testing equipment, portable magnetic flaw detector, pentrant, eddy current flaw detector and acoustic emission testing instrument. The quality of these products is very good. The operating function of these products is very stable and reliable.

(3) Many advanced NDT&E technique such as RT real-time imaging, TOFD ultrasonic test, ultrasonic phase array, ultrasonic guided wave test, pulsed eddy current test, magnetic flux leakage test, metal magnetic memory test, acoustic emission test, infrared/thermal test are being studied, developed and applied.

(4) Due to there are many new big engineering projects being on construction and the mechanical manufacturing industry is very active, China not only has a large requirement for conventional NDT instrument and materials, but also for advanced instruments, techniques and services.

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