IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 07, Issue 10 (October. 2017), ||V1|| PP 42-49

Primary level ultrasonic power measurement by radiation force balance (RFB) developed at National Institute of Standards (NIS)– Egypt

M. El-Gazery [1(*)] , A. H. Khafagy[2], G. M. Abd-Elssattar[1]
[1-] Ultrasonic Laboratory, National Institute for Standards NIS-EGYPT, El aharam Teresa, Giza, Egypt
[2-] Physics Department, Faculty of Science, Menoufia University, Shebin El-Koom, Egypt

Abstract: Medical ultrasonic is widely used in several medical applications for both diagnostic and physiotherapy as a result of its non-invasive and non-ionizing nature. The output power level of ultrasonic radiation must be well-known for both human being safety considerations and performance assessment of employed equipment. Before this work there was no primary level ultrasonic power measurements system to be used as a reference standard in Egypt, therefore, ultrasonic power measurement system based on the radiation force balance method (RFB)is developed and realized inthe National Institute of Standards (NIS) in Egypt. NIS is the Egyptian National Metrology Institute (NMI) that is responsible to develop and offer such kind of measurement and calibration services. The system was developed according to the IEC Standard 61161 (Arrangement E), to measure power values in the range from 10mW to 15 W, at operating frequencies between 1.8 MHz and 15 MHz with less than7% uncertainty. The system was calibrated against an ultrasound reference standard source received from the Korean Research Institute of Standards and Science (KRISS). The measurements were analyzed and presented in this work. The NIS system measurement results are within the accepted and internationally recognized uncertainty and measurement capabilities range.

Keywords: *Ultrasound; Acoustic power; measurement; radiationforce.*
[(*)]the corresponding author: -Ultrasonic Laboratory, National Institute for Standards (NIS)-EGYPT, El haram Tersa, Giza, Egypt , E -mail: elgazery_nis@hotmail.com

---

Date of Submission: 02-10-2017 Date of acceptance: 27-10-2017

I. INTRODUCTION

In the past years, ultrasound has been widely used in various medical applications as it is non-invasive and doesn't employ ionizing radiation. Those applications range from diagnostic imaging and blood flow measurement to therapy and surgery. Output power values from medical ultrasonic equipment range from microwatts for diagnostic to several watts for physiotherapeutic purposes [1-5]. However, exposure to relatively high power ultrasonic radiation may cause some damage effects (thermal and mechanical) to human tissues [5, 6]. Therefore, the necessity for measuring and regulating the output level of ultrasonic radiation has become very important matter for both human safety and assessment of the performance of medical equipment.

There are several published methods which can be used for obtaining the ultrasound output parameters, including calorimetric methods [7, 8], scanning by piezoelectric hydrophone [9], thermo-acoustic [10], acousto-optic [11], electro- acoustic efficiency of transducers [12] , and radiation force balance (RFB) method [13, 14]. Among all those methods, the RFB under the IEC Standard 61161 [15] is widely recognized and it is also used by National Metrology Institutes (NMIs) over worldwide [16-34] as it is the most reliable and reproducible method of the highest metrological qualities [14].

Because, there is currently no primary level ultrasonic power measurement system to be used as a standard in Egypt, the object of the present work is to develop and realize an ultrasonic power measurement system, based on the radiation force balance method (RFB) at the National Institute of Standards (NIS) in Egypt. This system is developed according to the IEC Standard 61161 (Arrangement E), to measure power values in the range from 10mW to 15 W, at operating frequencies between1.8 MHz and 15 MHz. Also, this system will be used to calibrate the ultrasound therapeutic transducers besides to check the good operation of diagnostic equipment in regional hospitals and clinics near around.

II. EXPERIMENTAL

2.1 Description and realization of the system

The schematic diagram of the developed primary ultrasonic power measurement system of NIS- Egypt, as well as, its photograph, are shown in Figs. 1 and 2, respectively.

The system is based on the radiation force balance method according to the IEC Standard 61161 [15] (as an Arrangement E) and consists of the main following parts:

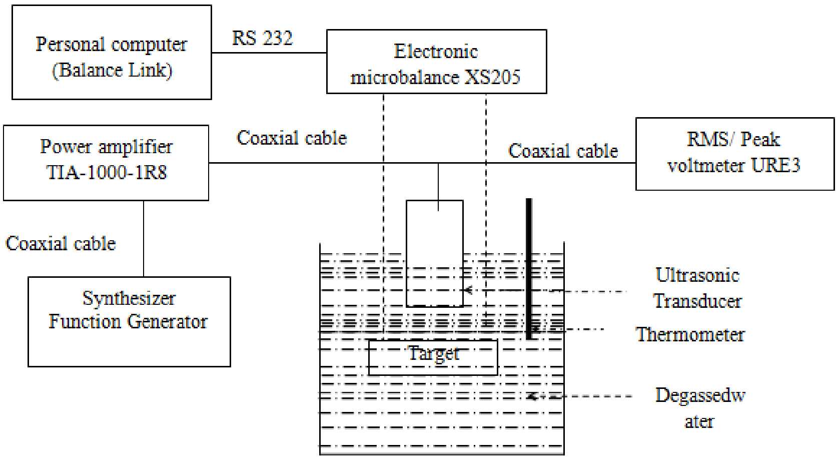

Fig. (1) A schematic diagram of the primary RFB system at NIS of Egypt

i) Water tank:

It is made from acrylic material in a cubic shaped 15 cm length, which was filled with degassed water to diminish cavitation effects.

Degassing of water in the tank was performed by adding sodium sulphite Na_2O_3 with a concentration 4g/l. This reduces the oxygen content in water [15, 35] for 2-4 days as it verified using dissolved Oxygen meter model DO200. Also, the water temperature was monitored by using a precision plus thermometer with a calibrated probe sensor placed inside the water.

Fig. 2: A photograph of the primary RFB system at NIS of Egypt.

1: Computer, 2: Function generator, 3: RMS/PEAK Voltmeter, 4: Power amplifier, 5: Balance, 6: Water tank, 7: ultrasonic reference source, 8: translation stage, 9: enclosure.

ii) The ultrasonic reference Source:

An ultrasonic reference source was established in the Korean Research Institute of Standards and Science (KRISS) [28]. This employed reference standard transducer has its identification number as KRISS 2MHz 14 LN and it was intended to be operated at its fundamental resonance frequency and the third, fifth and seventh harmonics. It has circular front face contains the active element which is a gold plated, air backed, narrow band, half wave resonant lithium niobate crystal of coaxial electrode design. The transducer rear is provided with a (female) BNC connector for the excitation voltage. The central lead of the connector is directly connected with the rear, “hot” electrode of the crystal. This means that the transducer does not contain any electronic components and is not matched to50Ωimpedance. The transducer is of cylindrical shape, 30mm outer diameter, about 102mm in length, and with a mass of about 114g. The transducer is covered by a red rubber cap for protection. It was positioned above the target as seen in Fig. 1 and radiates downward during its operation by turning it on. The transducer under test is fixed by a holder allowing the distance between the opposite surfaces of both the absorbed target and transducer to be controlled and adjusted as required. A continuous wave sinusoidal excitation voltage must be applied to the transducer. However, there were four voltage levels namely “very low” , “low”, “medium” and “high” which are indicated as well as the specified frequencies of operation in table (1).

Table (1): Specified values of operating ultrasonic frequency F_s and corresponding levels of applied voltage U_s.

FPL	F_s (MHz)	Level	U_s
A	1.8861	Very Low	1.30
B		Medium	17.00
C		High	50.00
D	6.3318	Very Low	1.24
E		Low	4.00
F	10.6284	Very Low	1.24
G		Low	4.00
H	14.9085	Low	3.70

iii) Target:

The used target is absorbed type and made from HAM-A as an acoustic absorber material, National Physical Laboratory (NPL) UK [29]. It is a circular disc with a diameter of 67 mm and 14 mm thickness. It was suspended, under the ultrasonic transducer in the degassed water by a thin nylon wire which is connected to an electronic microbalance. It is worth, mentioning that the plane surface of this target is usually concentric and well parallel to the face of the employed ultrasonic transducer under measurement.

iv) ExcitationVoltage

Those include an RF function generator model 3325B, used to provide the required input electrical signal to excite the ultrasonic transducer. This generator has its output frequency ranging from 0 to 40MHz and voltage ranges from $0V_{pp}$to$10V_{pp}$ ($3.5V_{rms}$). However, the required high signal voltage amplitude is achieved by using an E&I 2200L RF amplifier. Also, measurements of applied voltage amplitudes were carried out by using a RMS / peak voltmeter URE3.

v) The weighing balance:

The electronic microbalance used in the RFB system of this work was Mettler Toledo XS205 Dual Rang Max 81 / 220 mg and d =0.01/0.1mg. At the start, both of the weighing balance and the absorbing target are leveled before use. Also, the balance, tank and transducer are covered by a Plexiglas enclosure to prevent air disturbance. Besides, the supporting platform of the system is isolated from external vibrations and the electronic units of the ultrasonic transducer and that for data analysis are separated from the system to avoid unnecessary heat or vibration disturbances.

2.2 Acoustic power and radiation conductance calculation

The method of measuring acoustic poweris done through the measurement of the acousticradiation force, defined as the time-averaged force exerted by an acoustic field on any object intercepting the field, either partially or completely. If the assumption is made that the target is effectively infinite in size and absorbing, then the resultant radiation force, F, can be related to the output acoustic power, P_{out}, in the ultrasonic beam through the simple equation.

$$P_{out} = c.F \ldots\ldots\ldots\ldots \quad (1)$$

Where, c is the speed of sound in the relevant medium, commonly water, which is temperature dependent. Since, F is given by[36]:

$$F = \Delta m.g = |m_{on} - m_{off}|.g \ldots\ldots\ldots\ldots (2)$$

Where, m_{on} and m_{off} are the balance readings when the transducer is switched on and off, respectively and g is the acceleration due to gravity, which equals to 9.792999 m/s^2 at the Laboratory of mass, density and pressure in NIS of Egypt.

The electro-acoustic radiation conductance, G, is then given by [37,38]:

$$G = {P_{out}}/{U^2} \quad \ldots\ldots\ldots \quad (3)$$

Where, U is the root mean square (rms) voltage applied to the ultrasonic transducer. G is a characteristic parameter, which remains constant at a given frequency within the linear range of the ultrasonic output. It can be used by the manufacturer to produce the needed acoustic power by feeding the desired input voltage U according to equation (3).

2.3 **Measurement Realization and traceability.**

The time-averaged ultrasonic output power emitted by the standard ultrasonic transducer was calculated and thus the radiation conductance G (mS) values are determined according equation (3) under the specified conditions of electric excitation voltages in the nominal frequency range, 1.8 MHz to 15 MHz.

For validation purposes, the calibrated standard reference source supplied by KRISS was used and measurements were carried out at the NIS of Egyp tunder the same operation conditions of frequencies and corresponding applied voltages which are seen in table (1). The measurements results of the reference source were checked for performance stability and calibrated against the KRISS standard measurements of the same reference source as obtained under same operating conditions and both results for the radiation conductance and expanded uncertainty are shown in table (2).

Table (2): Comparison between preliminary results of radiation conductance G (mS) and expanded uncertainty ku (%) obtained NIS and KRISSreference values

FPL	NIS		KRISS Reference Value	
	G (mS)	ku (%)	G (ms)	u (mS)
A	5.73	5.9	6.74	0.11
B	5.81	4.7	5.49	0.10
C	NA	NA	5.69	0.11
D	6.22	6.7	6.90	0.14
E	6.94	4.3	6.03	0.09
F	6.21	5.0	7.87	0.14
G	6.63	4.5	6.51	0.11
H	6.65	6.9	7.29	0.16

2.4 Measurement Method

2.4.1 Imperfect targets

A mismatch of the acoustic impedance between the absorbing material(HAM- A) used and the medium (water) may yield coherent reflections. A correction for this effect is applied by performing each measurement at two distances which are (1/4) λ separated and averaging the results. The radiation conductance G, which is the ultrasonic power P divided by the square of the rms value of the transducer input voltage U, as a function of the target distance. Therefore, the measurements were here made at two distances with (1/4) λ between them and the results were averaged.

2.4.2 Accurate V_{RMS} voltage measurements

Accurate measurements of rf voltage is one of the critical problems associated with the RFB system. Generally the ac voltage applied to the transducer is directly measured with the help of an ac voltmeter or digital oscilloscope [17]. Here in NIS, the actual voltage at the entrance of the transducer was measured using ROHDE&SCHWARZ URE3 RMS/PEAK micro-voltmeter. To get the accurate measurements, the URE3 voltmeter has to be calibrated at each applied frequency with voltages near to the applied voltages with the attached cable (considering it is a part of the device). A RMS/PEAK Voltmeter is calibrated using hp Synthesizer/ Function Generator. Calibration made at different points to show the linearity of that device. From the calibration curve, an equation is obtained to correct the voltage values used. Then, connection is made between RMS/Peak voltmeter, hp Synthesizer/ Function generator and RF power amplifier, which is used to amplify the voltage. This is performed by using a splitting T connector which used at the entrance of the transducer to connect the power amplifier and then display the actual voltage value on the screen of RMS/ Peak voltmeter. The curve represents the calibration at one point, for example.

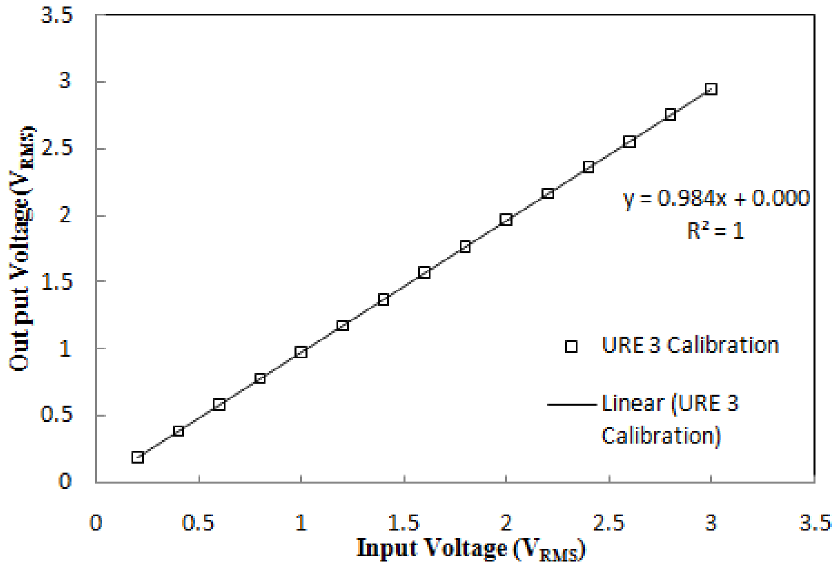

Fig.3 Calibration curve of URE3 voltmeter.

III. RESULTS AND DISCUSSION

As a matter of confirming compliance with the traceability requirements [15], for the reliability and validity of the primary ultrasonic radiation power measurement system developed at NIS of Egypt, it was an important and interesting thing to do such arrangement for making a comparison of direct results of output power data as resulted from the same reference transducer when it is employed by the different primary standard RFB systems as those ones which were previously mentioned in section 2.3 of this work.

Ultrasonic output power measurements were carried out at NIS laboratory using the radiation force balance method as recommended by the IEC 61161 [15]. The task was to measure the total time-averaged ultrasonic output power P_{out} emitted by the same identified ultrasonic transducer, mentioned previously, under specified conditions of electrical excitation into an anechoic (i.e., free field) water load. The output power at zero distance from the Transducer's surface was determined by calculating P_{out} at different distances between the absorbed target and the transducer and by extrapolation of the results, the electro-acoustic conductance G (mS) at zero is found.

However, Table (2) indicates the direct results, which obtained by NIS and the reference value Provided by KRISS, for both of the determined electro-acoustic conductance according to equation (3)and the calculated expanded uncertainty at the specified levels of applied voltage ,A,B,C,…….and H (see Table 1) .

With reference to the results presented in table (2), specially, those which correspond to NIS (column 2) they are average data of four separate measurements for each applied excitation voltage and operating frequency by resetting the ultrasonic transducer, the water path and the absorbed target completely.

Inspection of table (2) reveals that, the illustrated results represent the average values of acoustic conductance G (mS) and the expanded uncertainty ku (%),which were determined by all participants at four different specified frequencies, 1.8861, 6.3318, 10.6284 and 14.9085 MHz, under different levels of applied voltage of continuous AC signal (see table (1)). Although, there are slight fluctuations in some of the values of both of G (mS) and ku (%), at certain frequencies it is observed that the electro-acoustic conductance values resulted from the primary RFB measurements of NIS of Egypt (2^{th} column) are comparable with most of those ones of both participants as seen in columns 2, 3, 4 and 5 of table (2), where, good consistence between the listed results could generally be observed. Therefore, the above bilateral comparison results can enhance the verification as well as the validity of the primary RFB system developed at NIS of Egypt.

In addition to the above, the values of results of G(mS) for NIS and the reference value provided by KRISS measurements are plotted against their corresponding applied voltage levels (A, B, C, …….. and H) at the operating frequency power levels, FPL and shown in Fig. 4 with error bars indicate the uncertainties ku (G) , k=2. Looking at the results of this figure, for the sake of comparison, it can be seen that the average values of the ultrasonic radiation conductance of NIS are comparable to KRISS reference values for most of all frequency power levels (FPL) of applied voltages (indicated in Table (2)), which gives another confirmatory evidence for realization and validity of the RFB system developed at NIS of Egypt.
[1]

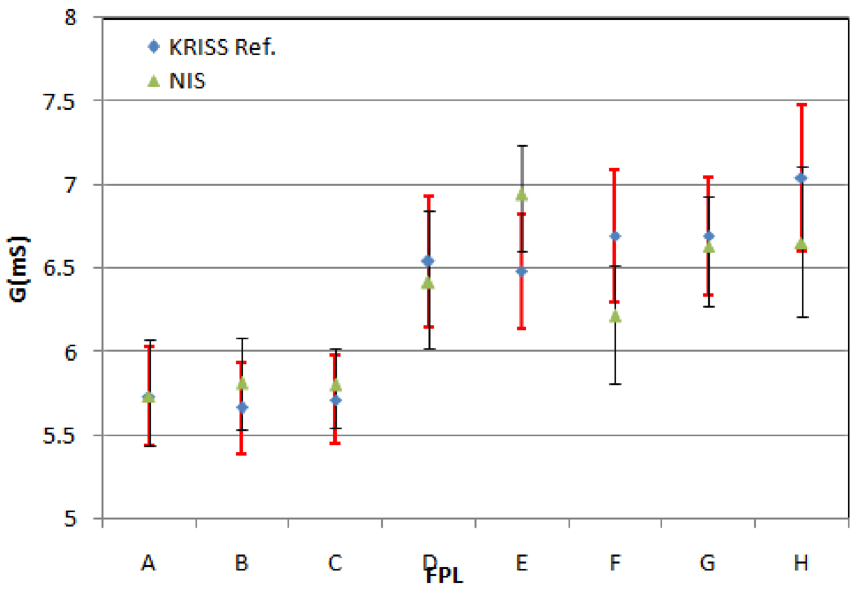

Fig.4: Results of G(mS) for NIS and the reference value provided by KRISS measurements are plotted against their corresponding applied voltage levels (A, B, C, …….. and H) at different operating frequency power levels, FPL, Error bars indicate the uncertainties k.u (G) (k=2).

Plans of future work will include great efforts to be done for increasing the service capacity (higher output power range with better resolution and more realization with gaining lower uncertainties

IV. CONCLUSION

In order to meet the requirements for the safety of ultrasonic medical devices, the ultrasonic power measurement system based on Radiation Force Balance method according to the IEC 61161 has been set up at NIS of Egypt. The average values of the ultrasonic radiation conductance and uncertainty of NIS are comparable to KRISS reference values for most of all frequency power levels (FPL) of applied voltages.

Plans for future work include increasing the service capacity (higher output power range) with better resolutions and lower uncertainties will be carried out with doing more efforts.

The primary level ultrasonic output power measurement service is open to be interested in doing research work related ultrasound purposes or applied metrology through agreements between educational institutes at all levels of education.

ACKNOWLEDGMENT

The authors would like to acknowledge and great thanks for the scientific cooperation and support provided by Dr. Yong Tae Kim and Dr. B. Y. Ahn- Korean Research Institute of Standards and Science (KRISS). Also, for giving the reference ultrasonic transducer to the Ultrasonic Lab at NIS of Egypt.

REFERENCES

[2] Tsuyoshi Shiina, S. Umchid, Frequency dependentultrasonic attenuation coefficient measurement, in the 3rd International Symposium on Biomedical Engineering (ISBME 2008),Bangkok, Thailand, P.P.234-238, (2008).

[3] S. Umchid, Directivity pattern measurement of ultrasound transducers, The International Journal on Applied Biomedical Engineering (IJABME), vol.2, P.P.39-43, (2009).

[4] S.Umchid, R.Gopinath, K.Srinivasan, P.A. Lewin,A.S.Daryoush,L.Bansal and M. El-Sherif, Development of calibration techniques for ultrasonic hydrophone probes in the frequency range from 1to 100MHz, Ultrasonics, vol.49, P.P.306-311, (2009).

[5] S. Umchid and K. Jaksukam, Development of the primary level ultrasound power measurement system in Thailand, in IEEE International Symposium on Biomedical Engineering (IEEE 2009),Bangkok, Thailand, (2009).

[6] S. Umchid and K. Jaksukam, K.Promasa and V.Plangsangmas, Ultrasound power measurement system using radiation force balance technique, in Biomedical Engineering International Conference (BMEi CON 2009) Phuket, Thailand, P.P. 254-257,(2009).

[7] F.Davidson, Ultrasonic power balances, in output measurements for medical ultrasound, R. Preston ED. Lodon: Springer- Verlag, P.P. 75-90, (1991).

[8] T.Kikuchi and T.Achida, Calorimetric method for measuring high ultrasonic power using water as a heating material, J.Phys. Conf.Ser. , 279 (2011).

[9] T.A.Delechar and R.J. Melvin, A Calorimeter for ultrasound total power measurements, Meas.Sci. Technol. , 5(1994).

[10] IEC Standard 62127-1 Ed.1, Ultrasonics- Hydrophones-Part1: Measurement and characterization of medical ultrasonic fields up to 40 MHz, International Electrotecnical Commission, Geneva (2007).

[11] B.Fay, M. Rinker and P.A. Lewin, Thermo-acoustic sensor for ultrasound power measurements and ultrasonic equipment calibration, ultras. Med. Biol. Vol.20,PP367-373,(1994).

[12] R.Reibold, W.Molkenstruk and K.M.Swamy“Experimental study of the integrated optical effect of ultrasonic fields”, Acustica vol. 43, pp253-259, (1979).

[13] S.Lin and F.Zhang, Measurement of ultrasonic power and electro acoustic efficiency of high power transducers, Ultrasonics,vol. 37,pp549-554, (2000).

[14] K.Beissner, Radiation force and force balance,in ultrasonic exposimetry, M.C.Ziskin and P.A.Lewin, Eds. Boca Raton CRC press,pp 163-168 (1993).

[15] K.Beissner, Primary measurement of ultrasonic power dissemination of ultrasonic power reference values by means of standard transducers, Meterologia vol.36, pp313-320(1999).

[16] IEC standard 61161 Ed.2, ultrasonics- Power measurement-Radiation force balances and performance requirements, International Electrotechnical commission,Geneva (2006).

[17] K.Jaksukam and S.Umchid, Aprimary level of ultrasonic power measurementdeveloped at national institute of metrology, Thialand, International Journal of Applied Biomedical Engineering, vol.4,No.1, pp 24-29, (2010)

[18] P.K.Dubey,Ashok Kumar, Yudhistherc Kumar, Reeta Gupta and Deepa Joshi, Primary measurement of total ultrasonic power with improved accuracy in rf voltage measurement, Review of scientific instrument 81, (2010).

[19] S.Cui, H.A.chua and C.K.Chan, Realization of medical ultrasound power measurement by radiation force balance method, National Metrology Center, Singapore, Metrology of Society of India, (2012).

[20] Marissa A.Rivera Carona, Anderé Victor Alvarenga and Rodrigo P.B.da Costa- Felix, Primary level ultrasonic output power measurement at laboratory of ultrasound of Inmetro,Metrology for a sustainable development, Septemper,17-22, Rio de Janerio, Barazil, (2006).

[21] S. E. Fick, The NIST Power Reference Source, in Ultrasonic Exposimetry, M. Ziskin and P. Lewin, eds, CRC Press, pp 169-183, (1992).

[22] S. E. Fick and D. Ruggles, In-Situ attenuation corrections for Radiation force measurements of high frequency ultrasound with a conical target, J. Res. Natl. Inst. Stand. Technol, Vol. 111, pp 435-442, (2006).

[23] S. E. Fick, Long term stability of the NIST Standard ultrasonic source, J. Res. Natl. Inst. Stand. Technol, Vol. 113, pp 281-286, (2006).

[24] K. Beissner, W.A. Oosterbaan, R. T. Hekkenberg,and A. Shaw,: European intercomparison of ultrasonic power measurements, Acustica / actaacustica, Vol. 82, pp 450-458, 671, (1996).

[25] K. Beissner, Intercomparison of acoustic output measurements of a diagnostic ultrasound device, ultrasound in Med. & Biol., Vol. 25, No. 4, pp. 629-636, (1999).

[26] R.C. Preston, Measurement and characterization of the acoustic output of medical ultrasonic equipment Part 2, Medical, biological Engineering & Computing, (1986).

[27] R.C. Preston, The NPL ultrasound beam calibrator. IEEE Trans. Ultrason. Ferroelectrics Frequency Control, Vol. 35, No. 2, pp 122–139, (1988).
[28] R. C. Preston, D. R. Bacon, and R. A. Smith, Calibration of medical ultrasonic equipment procedures and accuracy assessment. IEEE Trans. Ultrason. Ferroelectrics Frequency Control.Vol. 35, No. 2, pp 110–121, (1988).
[29] Report on Key Comparison CCAUV.U-K3 for Ultrasonic Power, Metrologia, 51 Tech. Suppl., (2014).
[30] B. Zeqiri andC. J. Bickley, A new anechoic material for medical ultrasonic application, Ultrasound Med Biol., Vol. 26, No. 3, pp 481– 485, (2000).
[31] Y. Sutton, A. Shaw and B. Zeqiri, Measurement of ultrasonic power using an acoustically absorbing well, Ultrasound Med. Biol., Vol. 29, No. 10, pp 1507-1513, (2003).
[32] A. Shaw, How to measure HIFU output power properly. In: Clement GT, McDannold NJ, Hynynen K, eds. Therapeutic ultrasound. Proceedings of the 5th International Symposium on therapeutic Ultrasound (AIP Conference Proceedings).Vol. 829. Melville, NY: American Institute of Physics, 628–632, (2006).
[33] B. Zeqiri, Metrology for ultrasonic applications, Progress in Biophysics & Molecular Biology, (2007).
[34] A. Shaw, A buoyancy method for the measurement of total ultrasound power generated by HIFU transducers, Ultrasound Med. Biol., Vol. 34, No. 8, pp 1327-1342,(2008).
[35] R.T. Hekkenberg, K. Beissner, B. Zeqiri, R. A. Bezemer and M. Hodnett, Validated ultrasonic power measurements up to 20 W, Ultrasound Med. Biol., Vol. 27, pp 427-438, (2001).
[36] R. T. Hekkenberg, K. Beissnerand B. Zeqiri, Therapy level ultrasonic power measurement, Final Technical report,SMT4- CT96-2139, (1999).
[37] S.E.Fick and F.R.Breckenridge J.Res, National inst. Standards and technology 101,pp659-669, (1996).
[38] T.Kikuchi, S.Sato and M.Yashioka,IEE Trans.Ultrason.Ferroelector.Frq.Control Conf. (50thUniversary Conf.)2197-2200 (2004).
[39] S.E.Fick, J.Res.Nat.Inst.Standards Technol. 113,pp 281-286 (2006).

M. El-Gazery Primary level ultrasonic power measurement by radiation force balance (RFB) developed at National Institute of Standards (NIS)– Egypt.” IOSR Journal of Engineering (IOSRJEN) , vol. 7, no. 10, 2017, pp. 42-49.