AN INSTRUMENT FOR MEASURING THE ABSOLUTE OUTPUT ACOUSTIC INTENSITY, EFFECTIVE RADIATING AREA AND BEAM NON-UNIFORMITY RATIO OF MEDICAL ULTRASOUND DEVICES

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ABSTRACT

A computer controlled Acoustic Intensity Measuring System (AIMS) is presented having performance and ease of use not heretofore available. Hardware and software performance criteria and design tradeoffs resulting from substantial experience with biomedical sound fields are presented.

The measurement of the absolute output acoustic field intensity parameters of diagnostic and therapeutic medical devices has always been difficult. In order to measure effectively, precise mechanical positioning, sound field sensing, data acquisition and elaborate data analysis are required. Additionally, a sophisticated, user friendly interface is important if less experienced technical staff will be operating the instrument. This last aspect is often not given the attention it deserves and, consequently, erroneous results may occur and remain undetected.

The Acoustic Intensity Measuring System (AIMS) presented here was developed over a period of several years for the purpose of measuring the acoustic output of commercially manufactured diagnostic and therapeutic ultrasound devices. These devices included vascular CW Dopler and catheter probes, abdominal and cardiac phased array systems, ophthalmic pulsed echo machines and high average power therapeutic applicators. The sound fields that it was required to measure ranged from a few millimeters to many centimeters in extent and had a frequency range of 1 to 20 Mhz.

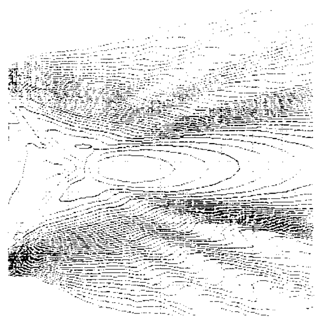
Our experience measuring this wide range of sound fields allowed us to define performance specifications that are adequate for essentially all practical ultrasound device measurement purposes, yet were realizable with a reasonable development effort. The following performance specifications were obtained:

1. 3 orthogonal axis (X,Y and Z) position translation of up to 10 by 10 by 20 inches with a 6.5 micron minimum step size.
2. Waveform acquisition with a 50 Mhz analog bandwidth and a maximum equivalent time sample rate of 5 Ghz.

Special features we consider essential for practical instruments are:

1. The ability to perform planar scans wherein the scan plane contains the acoustic beam axis.
2. The ability to easily add 2 polar axes of position rotation to the main positioner assembly at a later date.

"In plane" planar scans and resulting contour plots are the clearest way to visualize sound fields (see figure below) but require precise software control of the digitizer sampling trigger delay. The ability to rotate the hydrophone around two polar axes allows correction for directivity errors and automatic search and correction of acoustic beam axes misalignment.



"In Plane" Intensity Contour Plot of a 3 Mhz, highly focussed medical imaging transducer. The focal zone intensity maximum and beam sidelobes are clearly visible. Contour lines are at 1 dB intervals. Vertical scale is .6 inches and the Horizontal scale is 4 inches.

Required software features are:

1. Automatic search for spatial intensity maxima.
2. User selectable scan planes, dimensions and grid resolution.
3. Automatic calculation of all common field intensity parameters.
4. Automatic scans and calculations for hydrophone calibration.
5. User friendly, menu window operated user interface.
6. User selectable single "line scans".
7. Easy archiving of data and equipment setups.

The above listing is certainly not a complete, desirable feature list, but it does cover the most important ones. Clearly, software elements are very important to the performance and development of an AIMS instrument. Our experience is that software development time and cost is roughly triple that of the hardware. Because additional features are always being proposed and tested, software development expenses are expected to continue for the foreseeable future in our laboratory.

Basic system design issues required several difficult choices:

1. Open loop stepper control versus closed loop DC servo motor control.
2. Lead screw versus cable and pulley or timing chain positioners.
3. Equivalent time versus single shot waveform digitization.
4. System control computer and software language trade offs.

After careful analysis of the several performance specifications, we elected to use stepper motor drive with lead screw actuation. To guarantee non-slip stepping of the motors, without overheating, we designed custom electronic drive circuitry that substantially over-drives the motors while stepping and under-drives while position holding. Choosing lead screw drive allows absolute position accuracy of .001 inch over the mechanism travel range and accurate position retention upon system shutdown and startup. A lead screw pitch of 16 turns per inch and 200 steps per revolution motors gives 3200 steps per inch thus providing a minimum position step of 3 ten thousandths of an inch (6.5 micron). Testing with machinists dial indicators showed no position error creep due to step pulse slipping after many hours of continuous, 3 axes motion. Very high spatial resolution has proven to be important when measuring vascular and ophthalmic device sound fields which have very narrow focal zones. To fully utilize an AIMS with very high spatial accuracy and resolution, hydrophones of very small effective sensing diameter are required. After reviewing available hydrophones, we designed and built our own. It has an effective element diameter of .2 mm and is of the membrane type.

Broadband waveform digitization has evolved substantially in the last several years with both single shot and equivalent time sampling systems being offered by major instrument houses. Careful consideration of all the requirements and our own experience showed us that single shot digitization, though elegant, is not required in this application. Because our AIMS system was intended for commercial manufacture, we found the cost of off the shelf digitizers with adequate bandwidth (50 Mhz, 3 dB) too high. We built our own.

The AIMS system clearly requires a computer for control and data handling. Recent increases in performance and decreases in price for IBM PC compatibles made that our logical choice. Early results with PC-XT clones using monochrome monitors was unsatisfactory. The current AIMS uses a 10 Mhz PC-AT compatible with EGA graphics. The performance and price are quite acceptable.

Programming language choices for complex systems of this type include: C, Pascal, Basic, Forth and Modula-2. Each of these languages has its merit and difficulties. Microsoft's recently introduced Quick Basic was chosen. We have found this language to be versatile and comparatively easy to write programs in. Current work is in progress to convert the AIMS code to the Modula-2 language which we feel has more long term potential for the sophisticated software required in full function AIMS systems.

In conclusion, our work to develop a sophisticated tool for the general purpose measurement of ultrasound fields of the type produced by medical devices has been successful. Many systems have been built and are being used routinely in industry and academia. We believe that as AIMS instruments become more common in ultrasound laboratories, a wide range of new applications for them will be discovered.