

DMS-2350: SONOGRAPHIC INSTRUMENT/PHYSICS

Cuyahoga Community College

Viewing: DMS-2350 : Sonographic Instrument/Physics

Board of Trustees:

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Academic Term:

Fall 2024

Subject Code

DMS - Diagnostic Medical Sonography

Course Number:

2350

Title:

Sonographic Instrument/Physics

Catalog Description:

Physics and related mathematics as applied to ultrasound including the study of acoustical principles, sound transmission, signal processing, transducer construction, ultrasound instrumentation, quality assurance, and bioeffects of diagnostic ultrasound on soft tissue. Study of resolution, display modes, hemodynamics, Doppler principles and related instrumentation as it relates to ultrasound. Modular courses DMS-235A and DMS-235B will also meet the requirements for this course.

Credit Hour(s):

3

Lecture Hour(s):

3

Requisites

Prerequisite and Corequisite

DMS-1071 Concepts of Physics in Diagnostic Sonography; DMS-1311 Initial Sonographic Scanning; ENG-0995 Applied College Literacies, or appropriate score on English Placement Test.

Note: ENG-0990 Language Fundamentals II taken prior to Fall 2021 will also meet prerequisite requirements.

Outcomes

Course Outcome(s):

Apply knowledge of physical concepts of sound as it relates to ultrasound when performing sonographic scans.

Objective(s):

1. Describe the physical properties of sound.
2. Differentiate between an analog and digital signal describing advantages and disadvantages.
3. Describe the advantages of multi-crystal transducers configurations.
4. Describe the anatomy of an ultrasound beam and the factors that affect it.
5. Categorize the methods used to focus and steer the sound beam.
6. Define the piezoelectric and reverse piezoelectric effect.
7. Relate the various parts of the transducer construction to their purpose.
8. Explain the principles of pulsed ultrasound creation, the parameters that define a pulse and the factors that influence those parameters.
9. Describe the purpose of the various components that modify the returning echo.
10. Differentiate between an analog and digital signal describing advantages and disadvantages.
11. Describe the advantages of multi-crystal transducers configurations.

Course Outcome(s):

Applying knowledge of the various methods behind signal processing in the ultrasound system to the sonographic procedure.

Objective(s):

1. Identify the types of artifacts encountered in diagnostic ultrasound and state their probable causes.
2. Describe the various devices used to perform quality assurance on ultrasound equipment.
3. Explain the importance behind current research that describes how ultrasound produces bioeffects.
4. Explain the various types of ultrasound mode display forms.
5. Differentiate between the various types of resolution and indicate how to compensate for a decline in resolution.

Course Outcome(s):

Analyze the laws of fluid dynamics to its effects on the circulatory system.

Objective(s):

1. Distinguish how fluid, pressure, and resistance are interrelated.
2. Identify the various kinds of flow encountered in circulation.
3. Explain how stenosis affects blood flow.

Course Outcome(s):

Distinguish and differentiate between a normal and abnormal Doppler display.

Objective(s):

1. Explain the Doppler Effect and describe the interrelationships between the Doppler equation variables.
2. Evaluate Doppler images to provide a determination of the Doppler Effect.
3. Identify the various Doppler artifacts encountered in diagnostic ultrasound and explain probable causes.
4. Differentiate between the various methods of Doppler signal analysis.
5. Describe the basic principles of color flow Doppler.
6. Identify the instrumentation involved in color flow.
7. Determine whether color flow imaging, power Doppler imaging or duplex Doppler imaging is more appropriate in a given situation.

Methods of Evaluation:

1. Weekly quizzes
2. Weekly written assignments
3. Comprehensive mid term examination
4. QA project
5. Comprehensive final examination

Course Content Outline:

1. Concepts
 - a. Critical thinking
 - b. Sound properties
 - c. Sound beam
 - d. Transducers
 - e. Digital devices
 - f. Instrumentation
 - g. Artifacts
 - h. Bioeffects
 - i. Display modes
 - j. Resolution
 - k. Doppler
 - l. Hemodynamics
 - m. Quality assurance
2. Skills
 - a. Interpreting Doppler signals
 - b. Interpreting hemodynamic changes

- c. Manipulating machine adjustments for quality images
 - d. Maintaining safe machine operation
 - e. Developing risk versus benefit machine adjustments
 - f. Evaluating the performance of an ultrasound system with a phantom.
3. Issues
- a. Benefits
 - b. Limitations
 - c. Operator dependent
 - d. Quality assurance
 - e. Safety
 - f. Interpretation results
 - g. Atypical studies
 - h. Accuracy

Topical Outline

1. Review of basic mathematics
2. Review sound properties
 - a. Longitudinal mechanical waves
 - b. Pulsed Wave
 - c. Pulse production
 - d. Ultrasound transmission
3. Sound Beam
 - a. Formation - Near Field and Far Field (Fresnel and Fraunhofer Zones)
 - b. Interference phenomena
 - i. Huygen's principle
 - ii. Diffraction (divergence)
 - iii. Bandwidth
 - c. Length of near field (focal distance)
 - d. Shape of near field and far field
 - i. Beam width
 - ii. Natural focus
 - e. Dependence on frequency and crystal or aperture size
 - f. Beam steering
 - i. Transmission time delays
 - ii. Reception time delays
 - g. Beam focusing
 - i. Time delays
 - ii. Dynamic reception focus
 - iii. Multiple transmission foci
 - iv. Apodization
 - v. Subdicing
 - vi. Dynamic aperture
 - h. Clinical usage
 - i. On screen display
 - j. Identifying failure
4. Transducer Construction and Characteristics
 - a. Thickness resonance of crystal
 - b. Operating (resonance) frequency
 - i. Crystal thickness
 - ii. Speed of sound in crystal material
 - c. Frequency characteristics (spectrum)
 - i. Bandwidth
 1. Quality factor
 2. Effect of damping
 - ii. Multi-Hertz
 - iii. Harmonics
 - d. Damping
 - e. Matching layer-numerical example
5. Scanning Speed Limitations

- a. Applications of range equation and relationship to pulsing characteristics
- b. Real-time systems-relationships between
 - i. Pulsing characteristics
 - ii. Frame rate and time required to generate one frame
 - iii. Number of lines per frame
 - iv. Number of focal regions
 - v. Field of view (e.g., sector angle)
 - vi. Image depth (penetration)
- 6. Digital Devices
 - a. Binary system
 - i. Terminology (bits, bytes, pixels)
 - ii. Discrete nature of binary numbers
 - b. Steps in processing echo information
 - i. Analog-to-digital converter
 - ii. Digital memory
 - 1. Spatial resolution
 - a. Pixels
 - b. Matrix
 - c. Field of view
 - 2. Contrast resolution
 - iii. Digital-to-analog converter
 - iv. Display devices
- 7. Instrumentation
 - a. Signal types
 - i. Analog
 - ii. Digital
 - iii. Scan conversion
 - b. Transmitter (Output)
 - i. Effect of transmitter voltage on penetration
 - ii. Effect of transmitter voltage on intensity and on patient exposure
 - c. Receiver
 - i. Amplification
 - 1. Output power
 - 2. Receiver gain
 - ii. Compensation-time gain control (TGC)
 - iii. Compression and dynamic range
 - d. Demodulation
 - i. Rectification
 - ii. Smoothing (enveloping)
 - e. Rejection
 - f. Pre and post processing
 - i. Definition
 - ii. Preprocessing functions
 - 1. Time (depth) gain compensation
 - 2. Logarithmic compression
 - 3. Write magnification
 - iii. Postprocessing function
 - 1. Freeze frame
 - 2. Black/white inversion
 - 3. Read magnification
 - 4. Contrast variation
 - iv. Preprocessing or postprocessing functions (equipment manufacturer's discretion)
 - 1. Persistence
 - 2. Frame averaging
 - 3. Edge enhancement
 - 4. Smoothing
 - 5. Fill-in interpolation
- 8. Storage devices

- a. Video format
 - i. Display (monitors)
 - ii. TV monitors
 - 1. High resolution monitors
 - a. Lines and spatial resolution
 - b. Brightness
 - c. Contrast
 - d. Frame rate
 - iii. Single or multi-image cameras and laser imagers
 - 1. Photographic film
 - 2. Emulsion film
 - iv. Recorders
 - 1. Fiber-optic
 - 2. Videotape cassette
 - v. Printer
 - 1. Thermal
 - 2. Laser
 - b. Digital format
 - i. Magneto-optical disc (digital still recorder)
 - ii. PACS (Picture Archiving and Communication System)
 - c. Contrast and brightness control adjustments
9. Artifacts
- a. Definition
 - b. Artifact Recognition in Performing and Interpreting Examinations
 - i. Echoes not representing actual interfaces
 - ii. Missing echoes
 - iii. Misrepresented interface location
 - iv. Misrepresented interface amplitude
 - c. Artifacts Associated with Resolution and Propagation (Axial Resolution, Lateral Resolution, Section Thickness, Acoustic Speckle)
 - i. Definitions
 - ii. Mechanisms of Production
 - iii. Appearance
 - d. Artifacts Associated with Propagation (Reverberation, Comet-tail, Ring-down, Mirror Image, Multipath, Side Lobes, Grating Lobes, Refraction, Speed Error; and Range Ambiguity)
 - i. Definitions
 - ii. Mechanisms of Production
 - iii. Appearance
 - e. Artifacts Associated with Attenuation (Shadowing, Enhancement, and Focal Enhancement or Focal Banding)
 - i. Definitions
 - ii. Mechanisms of Production
 - iii. Appearance
 - f. Other (Electronic Noise, Equipment Malfunction)
 - i. Definitions
 - ii. Mechanisms of Production
 - iii. Appearance
 - g. Artifact Effects on Measurements (velocity or speed error and range ambiguity)
10. Quality Assurance of Ultrasound Instruments
- a. Need for and Nature of a Quality Assurance Program
 - b. Methods for Evaluating Instrument Performance
 - i. Test objects
 - ii. Phantoms (tissue, Doppler, flow)
 - c. Parameters to Be Evaluated
 - i. Test object
 - 1. Dead zone
 - 2. Axial resolution and lateral resolution (beam width)
 - 3. Depth calibration accuracy
 - 4. TGC characteristics
 - 5. Uniformity
 - 6. System sensitivity

- ii. Tissue equivalent (mimicking) phantom
 1. Dead zone
 2. Depth calibration accuracy
 3. Lateral (horizontal) distance measurement accuracy
 4. Axial, lateral, and section thickness (elevational) resolution
 5. TGC characteristics
 6. System sensitivity
 7. Dynamic range
 8. Contrast resolution
 9. Lesion detection
- iii. Doppler flow, string, or belt phantoms
 1. Maximum depth
 2. Pulsed Doppler sample volume alignment (gate position accuracy)
 3. Velocity accuracy
 4. Color flow penetration
 5. Image congruency test
- d. Preventive Equipment Maintenance
 - i. Cleaning
 - ii. Disinfecting
 - iii. Sterilization
- e. Record Keeping
- f. Statistical Indices
 - i. Sensitivity/specificity
 - ii. Negative/positive predictive value
 - iii. Accuracy
- 11. Bioeffects and Safety
 - a. Acoustic Output Quantities
 - i. Pressure
 1. Units
 2. Peak pressures
 3. Methods of determining pressure (miniature hydrophone)
 - ii. Power
 1. Units (mw)
 2. Methods of determining power (radiation force, hydrophone)
 - iii. Intensity
 1. Units (mW/cm², W/cm²)
 2. Spatial and temporal considerations
 3. Average and peak intensities
 4. Methods of determining intensity (hydrophones)
 5. Common intensities
 - a. SATA - spatial average temporal average
 - b. SPTA - spatial peak temporal average
 - c. SPPA - spatial peak pulse average
 - d. SPTP - spatial peak temporal peak
 6. Intensity and power values for different operating modes
 - b. Acoustic Output Labeling Standard
 - i. Thermal index
 1. TIS soft tissue thermal index
 2. TIB - bone thermal index
 3. TIC - cranial bone thermal index
 - ii. Mechanical index
 - c. Acoustic Exposure
 - i. Definition and concepts of prudent use (ALARA)
 - ii. Methods of reducing acoustic exposure
 - d. Primary Mechanisms of Biologic Effect Production
 - i. Cavitation mechanisms: relevant acoustic parameters
 - ii. Thermal mechanisms: relevant acoustic parameters
 - e. Experimental Biological Effect Studies

- i. Animal studies
 - ii. In vitro studies
 - iii. Epidemiologic studies
- f. Guidelines and Regulations
 - i. American Institute of Ultrasound in Medicine (AIUM) Statements e.g., mammalian, epidemiology, in vitro)
 - ii. National Electrical Manufacturers Association (NEMA)
 - iii. Food and Drug Administration (FDA)
- g. Electrical and Mechanical Hazards
 - i. Patient susceptibility to electrical hazard
 - ii. Equipment components which could present a hazard
- 12. Modes of display
 - a. Principal Display Modes (A-mode, B-mode, M-mode)
 - i. Definition of each mode
 - ii. Information displayed on each mode
 - iii. Advantages and disadvantages of each mode
 - b. Principles of Real-time Image Formation
 - i. Relationship between echo amplitude and B-mode display
 - ii. Positioning of echoes
 - iii. Harmonics
 - iv. 3-D and 4-D
- 13. Resolution
 - a. Axial Resolution
 - i. Dependence on spatial pulse length/ pulse duration
 - ii. Numerical example
 - iii. Effect of damping
 - iv. Transducer frequency spectrum-relation to pulse duration
 - v. Bandwidth
 - b. Lateral Resolution
 - i. Dependence on beam width
 - ii. Frequency
 - iii. Transducer size and focal characteristics
 - iv. Range
 - c. Slice Thickness Resolution (Elevational Resolution)
 - i. Dependence on beam width
 - ii. Transducer array and focal characteristics
 - iii. Frequency
 - iv. Lateral and axial resolution relationship
 - d. Temporal
 - i. Lines
 - ii. Frame
 - iii. Sector size
 - iv. Depth
 - v. Foci
 - vi. Pulse repetition frequency
- 14. Hemodynamics
 - a. Energy gradient
 - b. Effects of viscosity, friction, inertia
 - c. Pressure/volume/flow relationships
 - d. Velocity
 - e. Steady flow
 - i. Laminar
 - ii. Parabolic
 - iii. Disturbed
 - iv. Turbulence
 - 1. Eddies
 - 2. Reynold's number
 - f. Pulsatile flow
 - g. Stenosis

- i. Continuity Rule
 - ii. Bernoulli Effect
 - h. Venous resistance
 - i. Hydrostatic pressure
 - j. Effects of respiration (phasicity)
- 15. Doppler Physical Principles
 - a. Doppler Effect
 - i. Principle as related to sampling red blood cell movement
 - ii. Doppler equation
 - 1. Transmitted versus received
 - 2. Effect of source frequency on shift
 - 3. Effect of the angle on shift
 - 4. Effect of reflector velocity
 - b. Factors influencing the magnitude of the Doppler shift frequency
 - i. Range of the Doppler shift frequency
 - ii. Effects of beam angle, transmitted frequency, flow velocity, and flow direction
- 16. Doppler Instruments
 - a. Pulsed wave Doppler
 - i. Transducer construction
 - ii. Benefits
 - iii. Limitations
 - iv. Nyquist limit
 - v. Range ambiguity
 - b. Continuous wave Doppler
 - i. Transducer construction
 - ii. Benefits
 - iii. Limitations
 - iv. Uni- and bi- directional units
 - c. Instrumentation
 - i. Receiver
 - ii. Demodulator
 - iii. Wall filter for clutter rejection
 - iv. Directional devices
 - d. Duplex instruments-definition and basic principles
 - e. Spectral analysis
 - i. Purpose
 - 1. Direction
 - 2. Velocity
 - 3. Duration
 - 4. Character
 - 5. Magnitude
 - ii. Fast Fourier Transform (FFT)
 - iii. Diagnostic measurements (indices-i.e. pulsatility, resistive)
- 17. Color Flow Imaging
 - a. Basic Principles
 - i. Sampling methods
 - ii. Display of Doppler information
 - 1. Reflector direction
 - 2. Average velocity
 - 3. Velocity variance
 - iii. Advantages and limitations

Resources

Edelman, Sidney K. *Understanding Ultrasound Physics*. 4th ed. Dallas, TX: ESP, 2012.

Hedrick, Wayne R. *Technology for Diagnostic Sonography*. 1st ed. St. Louis, MO: Elsevier Science, 2012.

Kremkau, Frederick. *Diagnostic Ultrasound Principles and Instruments*. 10th ed. St. Louis: Saunders, 2020.

Miele, Frank R. *Ultrasound Physics & Instrumentation Volumes 1 & 2*. 6th ed. Forney, TX: Miele Enterprises, 2022.

Hoskins, Peter, Kevin Martin, Abigail Thrush, and Peter Hoskins, et al. *Diagnostic Ultrasound: Physics and Equipment*. 3rd ed. Boca Raton: Taylor and Francis Group, 2019.

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