The MDA-1000
Microwave Dielectric Analyzer
for
Industrial Process Monitoring and Control

The MDA-1000 System

The MDA-1000 measures the electromagnetic (dielectric) and numerous physical properties of materials such as bulk moisture content and density, contaminants, chemical reactions, porosity, thickness, structural characteristics and others. Patented contact sensors are used for on-line, continuous process monitoring of solids, particulates and liquids, or for in situ nondestructive testing with exceptional resolution. Near-line and off-line tabletop sensor systems are also available. Sensing is achieved by contacting an MDA-1000 sensor with the test material to measure small changes in the dielectric and loss properties at microwave frequencies. In turn, these electrical properties are diagnostic indicators of material physical properties.

Principles of Operation

The MDA-1000 sensor is an innovative, patented open reflection microwave resonator. When the sensor makes physical contact with the material under test, its resonant frequency and reflection coefficient (or return loss) at the resonant frequency are influenced by the dielectric constant (ε') and loss factor (ε'') of the test material. The analyzer drives the sensor with a low level microwave signal that is stepped through a narrow band of frequencies covering the sensor's resonant frequency. By monitoring the wave that is reflected from the sensor input, the sensor's resonant frequency and return loss are measured. From these two parameters, the dielectric components (ε', ε'') and/or certain other physical parameters (e.g., moisture content and density) can be determined [1, 2].

Sensor Heads

Sensor heads are often application specific, depending on whether the test material is a solid, a particulate or a liquid, on the range of (ε', ε''), on the material abrasiveness, on the desired spatial averaging, and on-line mounting constraints. Sensors are available in a variety of shapes; flat or curved for flush mounting to a plane or curved surface, or cylindrical for immersion in a flow stream or for manual insertion into liquids and granular materials. For nondestructive testing applications, the sensors can be configured for manual or automated mapping over material surfaces. Sensor size is also application specific, e.g., for liquids the sensors are usually about one inch in diameter, and for coarse particulates (such as wood chips) the sensors are about six inches long. The effective sensing depth ranges from a few millimeters to a few centimeters, chiefly determined by sensor size and design. Polarized sensors are available for measuring directional dielectric properties, such as when the test material contains aligned fibers. A thermocouple is used to compensate for the temperature dependence of (ε', ε''). Cure monitoring sensors operate at a maximum temperature of 230 ^{o}C (480 ^{o}F). Dual resonant frequency sensors can be provided for special applications, e.g., monitoring three independent properties simultaneously such as moisture, density and salt content.

Instrumentation

The MDA-1000 is a dedicated, industrialized microwave vector network analyzer, driven by a precision synthesized microwave power source. It features a high-directivity reflectometer and 60 dB dynamic range logarithmic amplifier for monitoring the wave reflected from the sensor input. A microprocessor controls the source stepping function while recording the resonant frequency and return loss of each sweep. Using a special software model and stored calibration coefficients, the dielectric components (ε', ε'') of the test material and the temperature-compensated physical parameters (e.g., moisture content and density) are computed.

The instrument is user controlled from a local control/display terminal. In addition, the data readout can be via a digital RS 232 link to a satellite computer, or a 4-20 mA analog signal. Solid state memory and a floppy drive (optional) stores data for back-up or later retrieval. The local or satelite display can be user-programmed to show, for example, time, date, product temperature, averaged moisture content and wet/dry densities. By time-shared multiplexing, (optional) one sensor on each of two parallel production lines can be monitored with the same instrument, but each sensor must be located within about eight feet of the instrument.

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Calibration

The MDA-1000 sensors are calibrated to measure (ε', ε") at the factory. Calibration of the MDA-1000 vs. material parameters (e.g., moisture and density) can be done on-line or at the factory depending on the application. Calibration coefficients as well as offsets and slopes of calibration curves for different sensors can be stored using the control/display terminal.

Accuracy, Resolution and Sensitivity

Accuracy is primarily determined by the accuracy of the primary standard method being used (e.g., weight-loss-on-drying), as well as by the application. Moisture content accuracies between 0.1% and 0.5% are typical. Resolutions are generally better by a factor of 1/2 or less. Liquids provide good surface contact with the sensor and are therefore measurable with the best accuracy. Surface roughness of solids and particle size of granular materials are other factors that affect accuracy and resolution. Spectrum smoothing and data averaging by the microprocessor can be used to good advantage.

Sensitivity is also application specific. It is best when the material being detected has contrasting dielectric properties (ε' and/or ε") compared to those of the host material. For example, free and molecularly bound moistures are highly polar at microwave frequencies (ε' ~ 68 and ε" ~ 20), while the dielectric properties of most organic and mineral materials are more than an order of magnitude lower. Also, sensitivity, accuracy and resolution improve with decreasing density (as well as ε' and/or ε") of the host material. At very low levels the moisture may become electronically bound, non-polar, and generally not detectable. Similarly, at sub-zero temperatures, all water becomes non-polar, although this abrupt transition occurs substantially below zero ^{o}C for most organic host materials.

Types of Measurements

Moisture Content: The MDA-1000 is particularly adept for measuring moisture in materials, compensated for material density. This is possible since both (ε', ε") are measured independently, and both are independent functions of the moisture and density. Note that the MDA-1000 measures the bulk properties, not just those at the material surface.

Cure Monitoring: Dielectric properties of thermoplastic and thermoset polymers vary widely during processing and chemical reaction. Both (ε', ε") have been shown to be inversely correlated to the polymer viscosity in the liquid state and to rigidity in the glassy state. When an MDA-1000 sensor is flush mounted in an autoclave mold, the state of the reaction can be monitored in real time from start to finish. Critical timing points in the process are easily identified and the degree of final cure measured. The MDA-1000 also signals the presence of moisture and porosity in the polymer. Both of the true dielectric dipolar parameters (ε', ε") are measured, not just the ionic conductivity as is common with low frequency cure monitoring instruments.

Nondestructive Testing: The MDA-1000 measures dielectric anomalies in high-value, dielectric and microwave absorbing materials such as advanced composites, ceramics, honeycombs and radomes. The signatures of these anomalies identify near surface voids, porosity, delaminations, cracks, moisture absorption, fiber/matrix material ratio, thickness variations, etc. Conductivities ranging over five orders can also be measured. Spatial resolutions of the order of 1mm can be achieved. 3D and contour relief maps of dielectric, conductive and structural anomalies can be created by manual or automated scanning of the sensor. Scanner and mapping software are optional.

Mixing/Emulsion Ratios: The ratio of component parts in two-part mixtures or emulsions can be measured provided they have significantly different dielectric properties.

[1] R.J. King, Ch 11 in Microwave Aquametry, IEEE Press, 1996

[2] R.J. King, Ch 5 in Sensors Update, V7, Wiley-VCH, 2000

Specifications

•Operating Frequency:	0.5 to 1.2 GHz in selected bands	
•Measured Parameter:	Reflection Coefficient	
•Moisture Accuracy:	0.1 to 0.5%, Application specific.	
•Resolution, Sensitivity:	(See technical description)	
•Control/Display		
-Local:	4 x 20 Char's LCD, Full Keybrd. 3 1/2 digit panel LED displ.	
-Satellite PC:	RS 232	
-Analog out:	4-20 mA	
•CPU Microprocessor:	486 or 586 w/ 1Mb RAM	
•Floppy Drive (option):	3.5", 2HD (1.44 MB)	
•Instrument:		
-Temperature:	0 to 65°C (32 to 150 ^{o}F)	
-Weight:	15 kg (33 lbs) in NEMA Encl.	
-Dimensions:	20.34 x 40.6 w x 40.6 L cm	
•Sensor	Application specific	
-Temperature:	< 230 ^{o}C (480 ^{o}F)	
-Weight:	0.23 kg (0.5 lbs.)	(typ)
-Dimensions:	1.9 H x 5 W x 10 L cm	(typ)
•RF Output Power:	< 15 mW	
•RF Connectors:	Type N	
•Primary Power:	Std. 110 VAC Single Phase, 50W	
•Enclosure:	NEMA to User's Specifications	

Technical Assistance

To learn how this new technology can help you solve your material sensing needs, contact a KDC engineer for immediate attention. At KDC you will find leading sensor technology and engineering solutions backed by strong, dedicated technical support.