GYROMAGNETIC SPECTROMETER HAVING A TAPERED DIELECTRIC TRANSITION BETWEEN A COAXIAL LINE AND A HELIX STRUCTURE

Filed Jan. 25, 1965 2 Sheets-Sheet 1

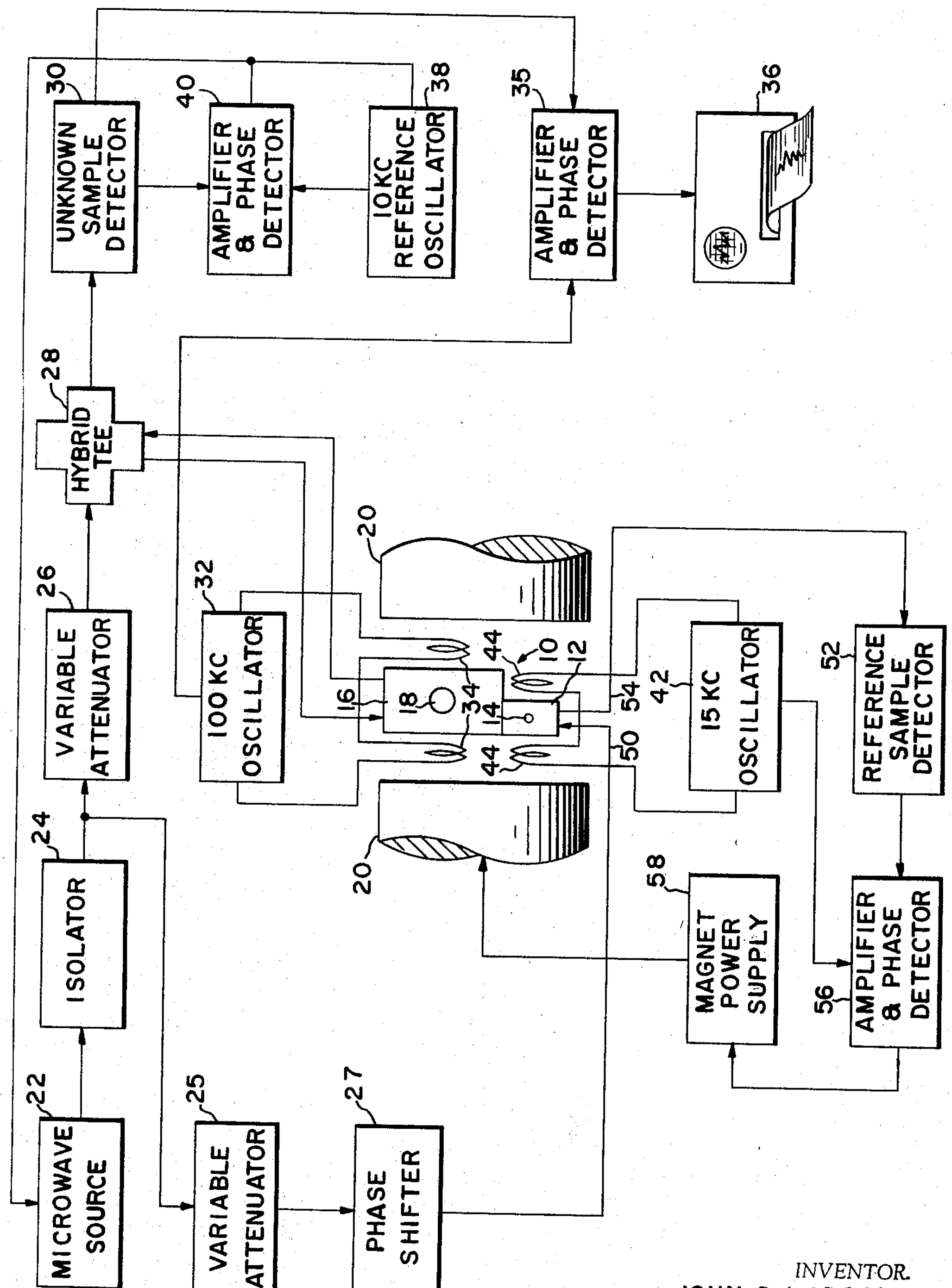

FIG.1

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FIG. 2

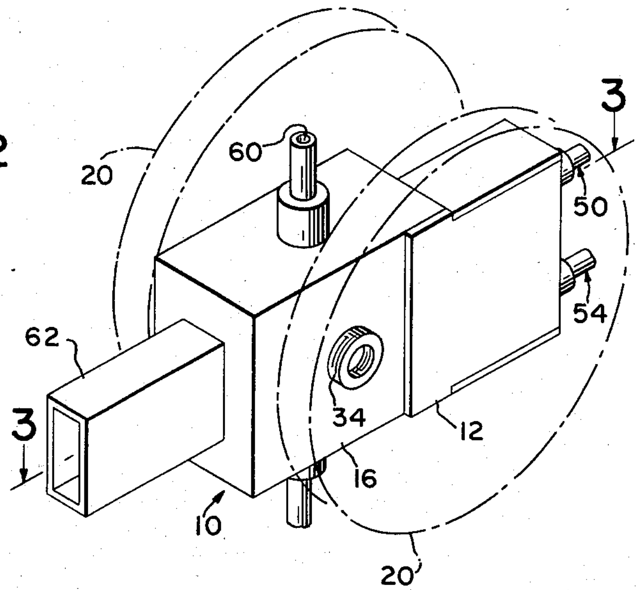


FIG. 3

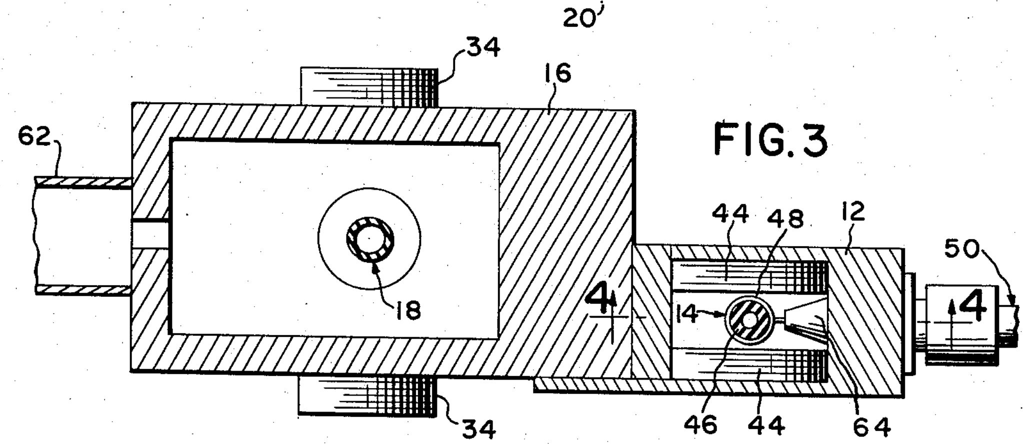
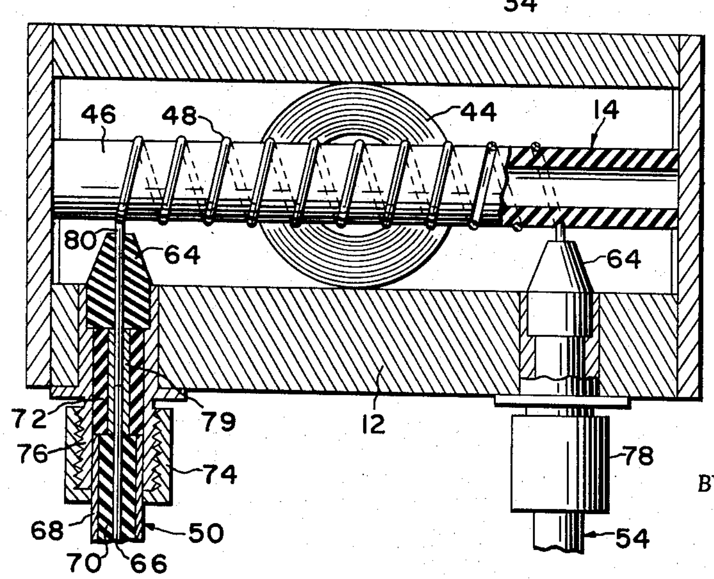


FIG. 4



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GYROMAGNETIC SPECTROMETER HAVING A TAPERED DIELECTRIC TRANSITION BETWEEN A COAXIAL LINE AND A HELIX STRUCTURE

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ABSTRACT OF THE DISCLOSURE

A gyromagnetic resonance spectrometer is disclosed for observing electron paramagnetic resonance of a sample under analysis. The spectrometer includes a probe structure having separate unknown sample and reference sample enclosures immersed in a common unidirectional polarizing magnetic field. Microwave energy is applied separately to both of the samples within their respective enclosures to excite resonance of both samples. Microwave energy is applied to the reference sample enclosure by means of a coaxial line coupled to a helix structure within the reference sample enclosure. The helix structure surrounds the reference sample and a tapered dielectric bead impedance matching transition is provided between the coaxial line and the helix structure. A second coaxial line is connected to the helix structure for observing resonance of the reference sample. A similar tapered dielectric bead impedance matching transition is provided between the output coaxial line and the helix structure. Various tapers are taught for the dielectric bead transition in order to obtain reflectionless impedance matches to the helix structure.

The present invention relates to an electrical energy coupling device, and in particular to a broadband frequency matching structure which may be used in an electron paramagnetic resonance (EPR) spectrometer, for example.

In one type of EPR system, such as described in U.S. patent application Ser. No. 198,898, filed May 31, 1962, now abandoned and assigned to the same assignee, a reference sample and a sample to be analyzed are both located within the same resonant microwave cavity structure so that the samples may be simultaneously excited to resonance by an external microwave power source. A coil or helix is wound around the tube which contains the reference sample, for receiving the microwave energy through a coaxial transmission line and for providing a reference resonance output signal. This output signal is recorded as a spectral peak with a stable reference value for comparison with the spectra derived from the analytical sample.

The cavity acts like a tuned circuit which has a very high Q, which Q is defined as ω (energy stored/power lost) and $\omega=2\pi$ times the frequency. When a resonance is obtained from the unknown sample, the impedance of the cavity is changed and a signal is reflected to a crystal detector in a hybrid T. When measurements are made at microwave frequencies, as in the case of electron paramagnetic resonance, accurate comparison between successive samples is exceedingly difficult due to errors resulting from sample-dependent changes in loading which affect such parameters as the cavity match, cavity Q, microwave phases and resonant frequency of the resonator structure used for irradiating the sample.

It is highly desirable that the impedances associated with the cavity be properly matched or else the detected resonance of the analytical sample may be inaccurate. Also it is preferable that there be a minimum of reflected

2

energy when power is fed from the microwave source into the cavity structure.

An object of the present invention is to provide a novel and improved electrical energy coupling device.

Another object of this invention is to provide a coupling device that affords a broadband frequency impedance matching structure.

Another object is to provide a coupler that serves as an impedance transformer between a coaxial input line and an inductive element.

In an embodiment of this invention, an EPR system includes a coupling device comprising a tapered dielectric structure disposed between a coaxial transmission line and a microwave circuit, which circuit may include a helical coil surrounding a sample to be excited to resonance, by way of example. For a detailed description of the use of helical coils in an EPR system, see the Review of Scientific Instruments, vol. 33, No. 7, July 1962, pages 732–737, an article entitled "Use of Traveling Wave Helices in ESR and Double Resonance Spectrometers" by R. Webb. The dielectric structure has an inner channel or bore wherein the inner conductor of the coaxial line may be seated for connection to one end of the coil. The connection is made by butt soldering, for example, so that the cross-section of the end of the coil is substantially parallel to the cross-section at the end of the coaxial inner conductor to which it is joined. The outer coaxial conductor is coupled through a metallic connector to a source of reference potential, such as ground. With this inventive assembly, optimum impedance matching is realized with minimum undesired reflected energy.

The invention will be described in greater detail with reference to the drawings in which:

FIG. 1 is a block diagram, partly in schematic, of an electron paramagnetic resonance system such as may incorporate the present invention;

FIG. 2 is an isometric view of a cavity structure, such as may be employed with the present inventive device;

FIG. 3 is a top view taken along lines 3—3 of FIG. 2; and

FIG. 4 is a sectional view taken along lines 4—4 of FIG. 3, and rotated clockwise 90°, depicting the novel structure of this invention.

Similar numerals refer to similar elements throughout the drawings.

With reference to the figures of the drawings, particularly FIG. 1, an EPR system comprises a cavity structure **10** which includes a nonmagnetic enclosure **12** for a reference sample **14** and a separate enclosure **16** containing a sample to be analyzed **18**. The cavity is located in a polarizing magnetic field H_0 provided by a magnet **20** so that both samples see substantially the same field.

Microwave energy is derived from a power source **22**, such as a klystron oscillator, and is passed through an isolator **24** and a variable attenuator **26** which controls the amount of power that is applied to the sample cavity. From attenuator **26**, the microwave energy is further channeled through a hybrid T **28** which serves as a balanced bridge in a well-known manner. Microwave power is directed from the hybrid T **28** to the cavity for exciting the sample **18** to resonance. A resonance signal from the unknown sample is received by a crystal detector **30** associated with one arm of the hybrid T **28**. At the same time, the microwave energy is directed from the isolator **24** through a directional coupler and wavguide structure (not shown) to a variable attenuator **25** and phase shifter **27** to the reference sample **14**. The phase shifter **27** affords detection of the dispersion or absorption mode of the EPR signal from the sample **14** and a reference crystal detector **52**.

Simultaneously, the field for the analytical sample **18** is modulated over a portion of the EPR line by means of an oscillator 32 and modulation coils 34, at a frequency of 100 kc./sec. by way of example. The modulation signal is also applied to an amplifier and phase detector 40 which is coupled to the sample detector 30. The detector 30 demodulates the microwave energy and provides a signal voltage, which contains EPR information. The frequency of this voltage corresponds to that of the 100 kc. sweep voltage used to modulate the polarizing magnetic field H_0. The demodulated signal from the detector 30 is compared to the modulation signal applied to the phase detector 35 from the oscillator 32, and as a result, a D.C. signal carrying EPR information is derived which is used for recording and visual indication on a recorder or oscilloscope 36.

The apparatus includes an automatic frequency control (AFC) circuit for stabilizing the frequency of the microwave source 22 to the resonant frequency of the cavity 10. To this end, a reference oscillator 38 feeds a 10 kc. reference signal to an amplifier and detector 40 and to the microwave source 22. This component of the signal is demodulated by the detector 30 and channeled to the phase detector 40 whereby a correcting voltage or AFC signal is derived. This signal is applied to the input circuit of the power source 22 for adjusting the frequency of the output from such source.

However, as the cavity 10 is heated due to high 100 kc. frequency power, the cavity 16 frequency will change and a shift away from magnetic resonance may occur. In such event, it is necessary to readjust the polarizing field H_0 in order to hold the detected EPR signal or spectral trace at the center of resonance and it is desirable to do this automatically. Therefore, the reference sample 14, which is located in the polarizing field H_0, is used whereby a proper ratio between the H_0 field and the frequency from the microwave source 22 is maintained. For this purpose, an oscillator 42 supplies a 15 kc. modulation signal to the polarizing field H_0 through a set of coils 44 positioned close to the reference sample 14.

The reference sample 14 which is contained in a vessel or tube 46 (see FIG. 4) is encompassed by a helix 48 that is connected at one end to a coaxial transmission line 50. In turn, the transmission line 50 is coupled to the source 22 through the phase shifter 27, variable attenuator 25 and isolator 24. The other end of the helix 48 is coupled to a reference sample detector 52 through a coaxial line 54. The signal detected by the detector 52 is amplified and phase detected in an amplifier and phase detector 56, which receives a 15 kc. reference signal from the oscillator 42. As a result, a D.C. signal is derived and fed to a magnet power supply 58 that supplies power to the magnet 20. In this manner, the intensity of the polarizing field H_0 may be varied with changes in frequency sensed by the helix 48 at the reference sample 14.

FIGS. 2 and 3 illustrate the cavity structure 10 which includes the reference sample enclosure 12 and analytical sample enclosure 16. Access means 60 are provided for insertion and removal of the analytical sample probe 18. A waveguide 62 associated with the hybrid T 28 is disposed at one end of the cavity for application of microwave power to the enclosure containing the analytical sample 18. On the other hand, microwave power is introduced to the reference sample enclosure 12 through the coaxial transmission line 50 coupled to the helix 48 surrounding the reference sample tube 46, as illustrated in FIG. 4. The modulation coils 34 for the analytical sample 18 are disposed externally of the analytical sample enclosure 16, whereas the modulation coils 44 for the reference sample are disposed within the reference enclosure 12.

In accordance with this invention, the coaxial transmission line 50 is coupled to the helix 48 by means of a tapered dielectric or insulator bead 64 which serves to reduce the reflected power from the helix to a small percentage of the power incident on the helix. Furthermore,

this reduction is achieved over a fairly wide frequency range, for example 8.2–12.4 kmc.

In one embodiment, the bead 64, which is made from Rexolite (manufactured by American Enka), has a dielectric constant of about 4, is approximately .170″ in diameter, about .270″ high, with a taper of less than 19° over .150″ of the height, for example. The inner channel or hollow of the bead is about .038″ in diameter to accommodate the inner conductor 66 of the coaxial line 50, and the small diameter of the tapered end is about .068″. These dimensions were found to provide optimum results. In another embodiment, which was successfully tested, a shorter bead used a taper between 19° to 35° over taper height of about 0.075″ with an overall height of approximately 0.195″.

When assembling the inventive combination, the outer conductor 68 and insulation 70 between the inner and outer conductors of the coaxial line 50 are stripped down so that a length of the inner conductor 66 is protruding. Thereafter, a dielectric cylindrical element 72 with a central bore and having substantially the same diameter as the coaxial line 50 is mounted onto the inner conductor 66. The inner conductor 66 is actually broken into 2 pieces. As part of the coupler 72, there is a metal sleeve 79. The inner conductor 66, and a connecting stub to a helix stem portion 80 are connected by the sleeve 79. A hollow cylindrical metallic plug 74, having an inner threaded portion, is positioned around the coaxial line 50 and a metallic coupler 76, having an outer reciprocating threaded portion, is passed over the dielectric cylinder 72 to engage the plug 74. Then the dielectric bead 64 is slipped over the inner conductor adjacent the cylindrical insulator 72 with a small portion of the inner conductor 66 protruding from the top end of the tapered bead 64. This conductor end is connected, by butt soldering for example, to an end of the helix 48. The connection is made so that the end of the inner conductor 66 and the end of the helix 48 being joined thereto provide substantially smooth parallel faces and thereby form a smooth continuous conductive path.

With this assembly, a conductive path is formed by the inner conductor 66 and helix 48, and a second conductive path is established by means of the outer conductor 68, metallic coupling parts 68, 74 and 76 which contact the metallic housing of the enclosure 12. The second conductive path and the enclosure 12 may be maintained at a reference potential, such as ground. Suitable insulation between the two conductive paths is provided by insulation 70, the element 72, and the dielectric bead 64. This coupling between the coaxial line 50 and the reference helix 48 serves to direct the input microwave signal to the reference sample. For channeling the modulated signal to the output circuit, a similar coupling 78 is employed at the other end of the helix 48.

By means of the inventive coupling assembly, it is possible to decouple the resonance of the resonance sample from the cavity resonance. The reference sample and its helix are disposed in a separate nonmagnetic enclosure, made from brass for example, such that the reference sample is not affected appreciably by the electrical energy or magnetic fields in the analytical sample enclosure. The particular frustoconical or tapered bead used in the assembly provides a most favorable impedance match between the coaxial transmission line and the reference helix. It is understood that various changes and modifications in the values and parameters set forth above may be made within the scope of this invention.

What is claimed is:

1. In a gyromagnetic resonance spectrometer, the combination comprising: a cavity resonator structure including a first enclosure, means for supporting an unknown sample within said first enclosure in a unidirectional magnetic field; a second separate enclosure, means for supporting a reference sample within said second enclosure in the same unidirectional magnetic field as the unknown

sample; means forming an electrical coil disposed in said second enclosure for encompassing the reference sample; means including a coaxial transmission line for coupling microwave energy to said electrical coil, said coupling means being connected to one end of said coil and comprising a tapered dielectric insulator bead positioned bebetween the coil end and the coaxial line, and means separate from said coil for coupling microwave energy into said first enclosure to the unknown sample to excite resonance thereof.

2. The combination as in claim 1 wherein the dielectric constant of said insulator is approximately 4.

3. The combination of claim 1 wherein the angle of taper of the insulator is less than 19° and the overall diameter of the insulator is about ⅔ of the overall height.

4. The combination as in claim 1 wherein the angle of taper of the insulator is aprroximately 35° and the overall diameter is about ⅓ of the overal height of the insulator.

5. The combination as in claim 1 wherein the angle of taper is between 19° and 35° and the overall diameter is between ⅓ and ⅔ of the overall height.

6. In a gyromagnetic resonance spectrometer, the combination comprising: a first resonator enclosure, means for securing an analytical sample probe within said first enclosure in a unidirectional magnetic field; waveguide means coupled to said first enclosure for providing microwave energy to said probe; first modulation coil means positioned externally to said first enclosure for providing a sweep signal to the analytical sample; a second, nonmagnetic enclosure separate from said first enclosure, means for supporting a reference sample in said second

enclosure in the same unidirectional magnetic field as the unknown sample; electrical circuit means disposed within said second enclosure and coupled to the reference sample for providing microwave energy thereto separate from the microwave energy applied to the unknown sample; second modulation coil means positioned internally of said non-magnetic enclosure for providing a sweep signal to the reference sample, said electrical circuit means including a coaxial transmission line external of said second enclosure for channeling microwave energy to said reference sample; and dielectric means disposed between the coaxial line and the reference sample for minimizing the reflectivity of the microwave energy.

7. The combination as in claim 6 further including electrical circuit means for passing a microwave signal from the reference sample out of the non-magnetic enclosure, including a second coaxial transmission line; and second dielectric means disposed between the reference sample and the second coaxial line.

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