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MICROWAVE DRYING SYSTEM USING PHASE SHIFTERS

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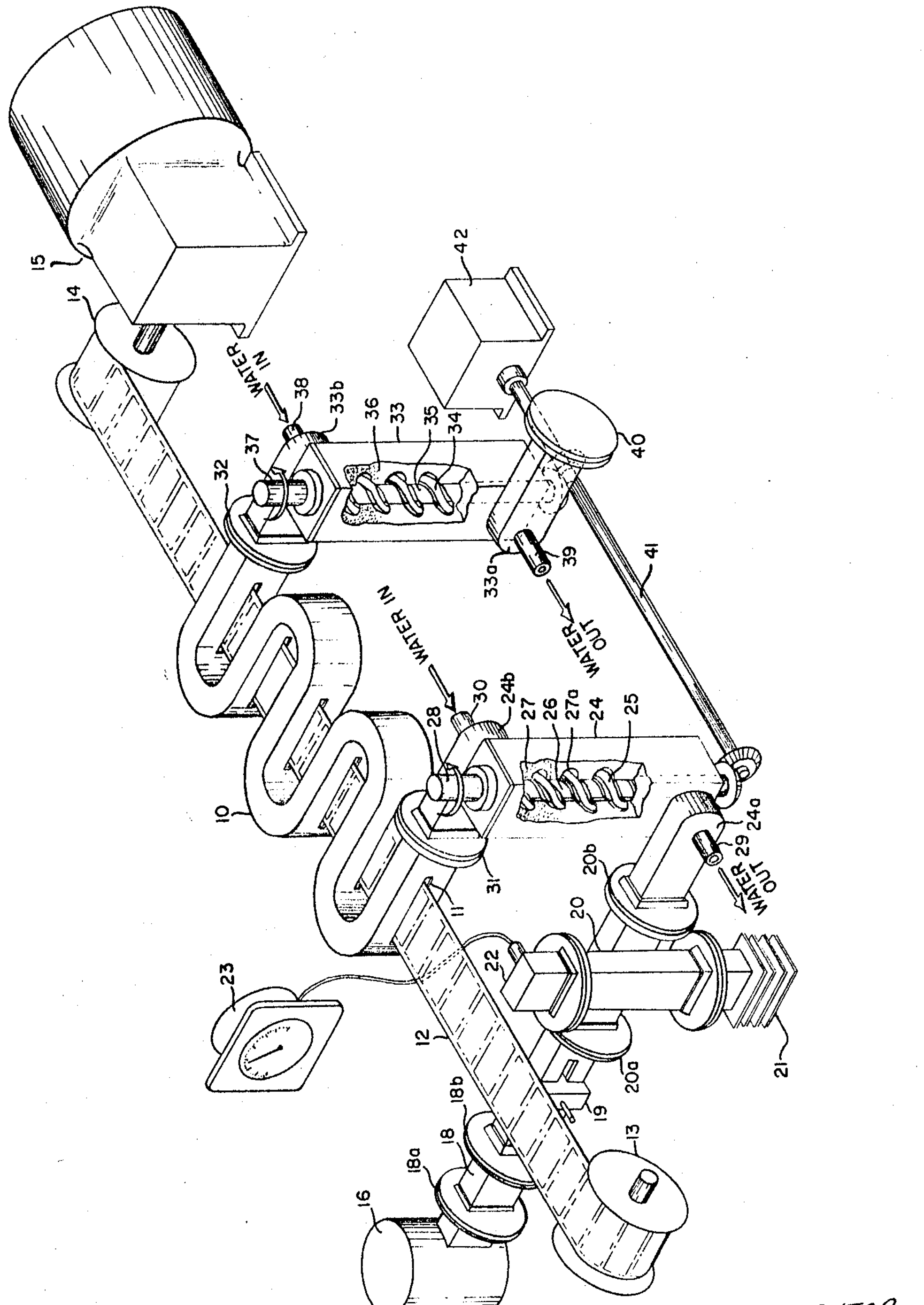

INVENTOR
WILLIAM J. BLEACKLEY
BY J. R. Hughes
AGENT

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MICROWAVE DRYING SYSTEM USING PHASE SHIFTERS

William J. Bleackley, Ottawa, Ontario, Canada, assignor to Canadian Patents and Development Limited, Ottawa, Ontario, Canada, a corporation of Canada

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ABSTRACT OF THE DISCLOSURE

A microwave drying system for film, paper, and the like of the type using a tuner in the input to provide a tuned circuit in the drying section wherein the undesirable effects of stationary standing waves on the material being dried are eliminated by cyclically shifting the standing wave pattern in the drying section by means of phase shifters placed ahead of and after the drying section.

This invention relates to a microwave drying system wherein the undesirable effects due to standing waves in the system are eliminated or greatly reduced.

Microwave energy is coming into widespread use for the rapid and efficient drying of many materials. It has been especially applied to the drying of lumber, paper, film, leather and many other materials that require moisture removed from them without particular damage to the material itself. In general the systems that have been developed for the drying of flat or web-like material such as paper and film involve a suitably electrically energized section of wave-guide with relatively narrow slots in the broad faces. The material to be dried passes through the interior of the wave-guide via the slots where the electric field differentially heats the water which evaporates out of the material and is removed by a stream of air. The water is highly lossy over much of the microwave frequency spectrum whereas the paper or film material is normally quite unaffected provided the system is such that there are no great concentrations of energy at certain points in the system. An efficient and rapid drying system may be readily designad using these concepts but great care must be exercised in the actual design of a workable unit.

In some drying systems, i.e., the travelling wave type, the energy after passing through the drying portions of the wave-guide is directed into a suitable termination or load that absorbs the excess energy. Ideally no standing waves are set up and there is no problem of "hot spots" and burning or injury to the material being dried. However, in the drying system using a short-circuit termination and a tuner at the input to provide a tuned or resonant circuit, standing waves are set up and these involve concentrations of microwave energy at localized positions across the material being dried. This can result in "hot spots" and the burning or injury to the material at these positions. The tuned or resonant system is most attractive from the economic viewpoint because all of the energy is used in the drying process with none being absorbed and lost in an energy absorbing load.

It is, therefore, an object of the present invention to provide a microwave drying system in which the effect of standing waves is eliminated or greatly reduced.

It is another object of the invention to provide a microwave drying system of the tuned type in which the undesirable effect of stationary standing waves is eliminated or greatly reduced but in which there are no adverse or upsetting effects on the tuning system and the microwave power supply.

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It is another object of the invention to provide a microwave drying system for paper, film, and the like that provides even drying action across the width of the material.

It is another object of the invention to provide a microwave drying system that is relatively easy to operate and that requires no complex, mechanical apparatus.

These and other objects of the invention are achieved by providing a microwave drying system for paper, film, and the like wherein the microwave energy before and after it passes through the drying portions of the system passes through phase shifters such that the standing waves in the system are reciprocated so that any undesirable effects that the standing waves might otherwise have on the material to be dried is averaged out, said phase shifters being interconnected such that no undersirable effect is placed on the energizing system.

In drawings which illustrate embodiments of the invention, the figure is an isometric view of a microwave drying system including phase-shifters.

Referring to the figure a microwave drying system is shown. A wave-guide **10** has a series of slots **11** through which passes a film **12** unwinding from reel **13** onto reel **14**, the latter being driven by a gear reduction motor **15**. As the film passes through the wave-guide, the microwave energy is absorbed by the water in the film and boils off as steam. The film itself is normally unaffected provided it is moved through the wave-guide at a reasonable speed and the wave-guide itself is terminated in a load or termination that absorbs any energy left after the drying process. If, however, there are standing waves existing in the wave-guide and this is normally always the case although usually much more definitely where the wave-guide is terminated in a short-circuit with the energy being reflected back along the guide, there is a tendency for hot spots to form due to the concentration of the electric field at the standing wave nodes. This results in burning or injury to the film or paper and is most undesirable.

The system is energized by a suitable power source **16**, e.g. magnetron. An isolator **18** inserted in the line by means of flanges **18***a* and **18***b* is used to protect the magnetron. A microwave tuner **19** is used to tune the wave-guide system to make it in effect a resonant circuit and to prevent reflections from reaching the power source. Although any good tuner might be used for this application, a type similar to that shown in United States Patent No. 3,110,-002, dated Nov. 5, 1963, and entitled "Variable Insertion Sliding Post-Slotted Line Tuner Having Means Preventing Energy Loss Past Sides of Post," would operate most suitably. A direction coupler **20** which is inserted in the line by means of flanges **20***a* and **20***b* connects to a detector **22** and suitable load **21**. The output of the detector is read on meter **23** to give the operator tuning information.

A first phase shifter **24** is located in the system ahead of the wave-guide **10** and comprises a helical assembly **26** mounted on shaft **28**. The helical assembly comprising a worm core of dielectric material rotates inside a co-axial cable **25** which is in the form of a cylindrical helix of pre-determined pitch mounted inside backing material **27** with a helical groove **27***a* left therebetween for passage of a coolant if necessary. Because the phase shifter involves a co-axial cable device provision is made for transition from wave-guide operation to co-axial cable inside housing **24***a* and in the reverse sense in housing **24***b*. Provision for the introduction of cooling water is made by inlet and outlet ducts **30** and **29**. The phase shifter is connected to the wave-guide **10** by suitable flange **31**. An identical phase shifter **33** is connected on the output end of the wave-guide system by flange **32** and incorporates worm core **35** mounted on shaft **37**, helical co-axial cable **34**, transition housings **33***a* and **33***b*, and coolant inlet and outlet ducts **38** and **39**. Both phase-shifters are driven from common-shaft **41** by suitable motor drive means **42**. The type of phase-shifter shown here is described in much more detail in United States Patent No. 3,145,353, dated Aug. 18, 1964 and entitled "Variable Delay Using Dielectric Screw Rotatable Inside Surrounding Helical Transmission Line," and reference should be made to that patent for more information on the theory of operation and construction of the device.

The complete system is terminated at **40** by a suitable short circuit termination. It will be realized that the system described above is most suitable for the drying of film where it is difficult or inconvenient to use all the energy in a "one way" operation, i.e., where the energy is largely used in the drying operation and any remaining power is absorbed by a suitable load or termination. It is desirable especially in the case of film to reflect the energy so that it will substantially all be used in the drying process. This latter mode of operation, however, involves the formation of standing wave patterns and the attendant difficulties described above.

In operation the two phase-shifters are driven in synchronism but 180° out of phase such that the phase is being shifted (advanced) at one and retarded at the other. The speed of rotation (phase shift) is chosen in relation to the speed of travel of the film or paper **12** and would be in the order of 1200 to 1800 r.p.m. for a typical case. The complementary action of the phase shifters is such that the standing wave pattern in wave-guide **10** oscillates or cyclically moves along its length (across the width of the film **10**) and any tendency for burning or injury to the film or material is averaged or cancelled out.

Other forms of phase-shifters may be used but they must be able to handle the relatively large amounts of power involved in these systems and they must be able to operate sufficiently quickly in relation of film transport speed to be effective. Mechanical devices such as line stretchers, trombone sections, etc. might be used but the above considerations largely dictate against their ready use. Electrical phase shifters are, therefore, much more convenient but must be able to operate in complementary fashion as described above. It will be realized that although the phase shifters alter the standing wave patterns inside the drying portions of the wave-guide system no effect is seen by the power source or the termination.

What is claimed is:

1. A microwave drying system for film, paper, and the like comprising:

(a) a wave-guide section having slots in its broad faces for the passage of the material to be dried, and which when energized generates a standing wave pattern,

(b) a microwave power source connected to said wave-guide section for electrically energizing it such that moisture in the material to be dried will differentially absorb the microwave energy and evaporate off,

(c) a short circuit termination terminating said wave-guide section,

(d) a first phase shifter inserted in the system between said power source and said wave-guide section and,

(e) a second phase shifter inserted in the system between said wave-guide section and said termination,

(f) said first and second phase shifters being operated in synchronous out-of-phase relation such that the phase at one is being advanced while the phase at the other is being retarded.

2. A microwave drying system as in claim **1** wherein the means for shifting the standing wave pattern are electrical phase-shifters.

3. A microwave drying system as in claim **1** wherein the phase shifters comprise a helical worm of high loss tangent dielectric material rotating inside a helical co-axial cable, the said cable having a recess cut on its inner surface such as to electrically expose the inner conductor of the co-axial cable to the said worm.

4. In a microwave drying system of the type wherein the material to be dried is passed, through an electrically energized short circuit terminated wave-guide such that microwave energy is absorbed by the moisture in the material, the improvement comprising means for cyclically shifting the phase of the standing wave pattern in the wave-guide said means comprising a phase shifter inserted in the system ahead of the drying wave-guide and a phase shifter inserted in the system after the drying wave-guide, said phase shifters being operated such that the phase is being advanced at one while being retarded at the other.

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JOSEPH V. TRUHE, Primary Examiner

L. H. BENDER, Assistant Examiner

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