United States Patent [19]

Nagao et al.

[11] **3,761,665**

[45] **Sept. 25, 1973**

[54] **MICROWAVE HEATING APPARATUS WITH LOOPED WAVE GUIDE AND PHASE SHIFTING MEANS**

[75] Inventors: **Tsuguki Nagao**, Tokyo; **Tomiji Okakura**, Yokohama; **Kazunori Hasegawa**, Kanagawa, all of Japan

[73] Assignee: **Tokyo Shibaura Electric Co., Ltd.**, Kawasaki, Japan

[22] Filed: **May 25, 1972**

[21] Appl. No.: **257,017**

[52] **U.S. Cl.** **219/10.55**

[51] **Int. Cl.** **H05b 9/06**

[58] **Field of Search** 219/10.55

[56] **References Cited**

UNITED STATES PATENTS

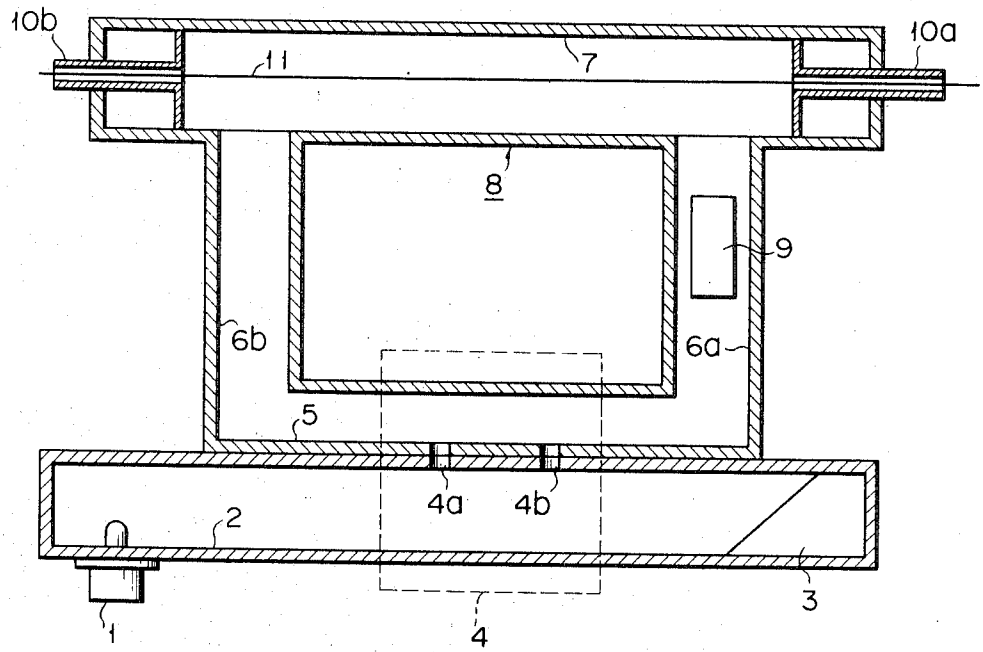
3,529,115	9/1970	Jawor	219/10.55
3,590,202	6/1971	Day et al.	219/10.55
3,670,133	6/1971	Admiraal	219/10.55
3,571,551	3/1971	Ogasawara	219/10.55

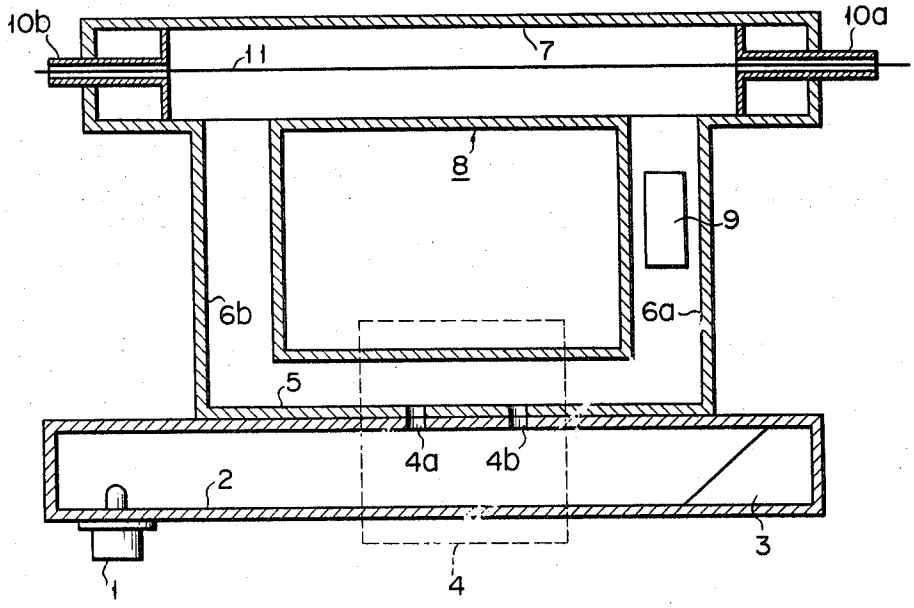
Primary Examiner—R. F. Staubly
Assistant Examiner—Hugh D. Jaeger
Attorney—Robert D. Flynn et al.

[57] **ABSTRACT**

A microwave heating apparatus comprises a directional coupler including a main wave guide receiving energy from a microwave oscillator and a supplementary wave guide coupled to the main wave guide and receiving microwave energy therefrom. A heating wave guide preferably provided with a movable short-circuiting plate at both ends is connected to the supplementary wave guide so as to transmit in the TM mode the microwaves generated by the microwave oscillator and conducted thereto through the directional coupler. A variable phase shifter is provided for bringing the microwaves fed back to the supplementary wave guide through the heating wave guide in-phase with the microwaves conducted to said supplementary wave guide from the microwave oscillator.

9 Claims, 1 Drawing Figure




10b
10a
11
7
8
9
6b
6a
5
4a
4b
2
3
1
4

MICROWAVE HEATING APPARATUS WITH LOOPED WAVE GUIDE AND PHASE SHIFTING MEANS

BACKGROUND OF THE INVENTION

This invention relates to a microwave heating apparatus provided with a microwave feedback circuit.

Synthetic fibers generally have to be subjected to heat treatment after spinning for improvement of quality. To this end, there is customarily used a heating furnace utilizing electromagnetic waves having a high frequency of scores of MHz, hot water or hot air. With heating temperature and the feed rate of an object fixed, then an increase of the overall amount of heat applied would make it necessary to lengthen a furnace. Moreover, a hot air furnace only heats the surface of fibers, failing to impart a great tensile strength to fibers treated. When fine fibers which are twisted like a rope are heated, there is applied either high frequency waves of scores of MHz or hot water or both. Use of hot water alone does not fully provide high enough treating temperature, thus failing to improve the strength of fibers treated. Application of only high frequency waves of scores of MHz to fibers having a small loss factor such as those of polyester only attain an extremely low heat efficiency. Fibers having a medium loss factor like those of Nylon are first treated with hot water to raise their temperature (generally, the higher the temperature, the larger the loss factor) and later heated with high frequency waves. In this case, water is attached to fibers during hot water heating, so that in the succeeding heat treatment with high frequency waves, a great deal of the high frequency energy is consumed in order to remove the water first, also leading to a low heating efficiency.

In recent years, therefore, fine fibers have been heated by an apparatus utilizing microwaves of far higher frequency. For fibers less than 2 mm in diameter with a small loss factor, however, such apparatus fails efficiently use the microwave energy causing heat to be uselessly released from the surface of the fibers and presenting difficulties in heating them to a high enough temperature. For satisfactory heat treatment, therefore, it is necessary to prolong the treating time on said apparatus or enlarge its size. It may be contemplated to provide for the presence of standing waves in a heating furnace so as to effectively heat the above-mentioned type of fiber. This method, however, will cause the fibers to be unevenly heated along the node and antinode of standing waves and, if the fibers are extremely fine, possibly give rise to their breakage due to melting during heat treatment.

Accordingly, this invention is intended to provide a microwave heating apparatus capable of heat treating an object quickly and efficiently.

SUMMARY OF THE INVENTION

According to a preferred aspect of this invention, there is provided a microwave heating apparatus comprising a microwave oscillator; a looped wave guide circuit for circulating microwaves received from the microwave oscillator in the same direction, said circuit including a heating wave guide for transmitting in the TM mode the microwaves conducted from the microwave oscillator to said circuit; and means for bringing the microwaves circulating through the looped wave guide circuit in-phase with the microwaves supplied to said circuit from the microwave oscillator, thereby efficiently heating an object introduced in the axial direction of the heating wave guide.

BRIEF DESCRIPTION OF THE DRAWING

The appended drawing is a schematic sectional view of a microwave heating apparatus according to an embodiment of this invention.

DETAILED DESCRIPTION OF THE INVENTION

There will now be described by reference to the appended drawing a microwave heating apparatus according to an embodiment of this invention.

Microwaves generated by a microwave oscillator **1** proceed through a main wave guide **2** toward a dummy load **3**. Microwaves received in the main wave guide **2** are conducted to a supplementary wave guide **5** communicating with the main wave guide **2** through two holes **4***a* and **4***b* spaced from each other to an extent of $\lambda g/4$ (λg represents the wave length of microwaves passing through the wave guides). The main wave guide **2**, supplementary wave guide **5** and holes **4***a* and **4***b* enclosed in the broken lines of the drawing constitute a directional coupler **4**. Microwaves brought into the supplementary wave guide **5** circulate through a connection wave guide **6***a*, circular heating wave guide **7**, connection wave guide **6***b* and supplementary wave guide **5** in turn, which collectively constitute a looped wave guide circuit **8**. According to this embodiment, there is disposed a variable phase shifter **9** in the connection wave guide **6***a* so as to bring the mirowaves circulating through the looped wave guide circuit **8** inphase with the microwaves conducted from the main wave guide **2** to the supplementary wave guide **5**. The variable phase shifter **9** is so adjusted as to cause the passageway of microwaves in the looped wave guide circuit **8** to have a length equivalently representing a value of $n\lambda g$ (n denotes a positive integral number). As a result, the microwaves passing through the looped wave guide circuit **8** and the microwaves supplied from the main wave guide **2** to the supplementary wave guide **5** reinforce each other to cause microwaves having a strong electric field to be transmitted toward the heating wave guide **7**. When the heating wave guides **6***a* and **6***b* are connected to the heating wave guide **7** at right angles, and the size of said heating wave guide **7** and the position of movable short-circuiting plates **10***a* and **10***b* at both ends of said wave guide **7** are properly chosen, then microwaves from the connection wave guide **6***a* travel through the heating wave guide **7** in the TM mode bearing an electric field along its axis. The energy of microwaves used in heating is generally proportionate to the square of the intensity of their electric field. Since microwaves carried through the heating wave guide **7** provide a strong electric field acting in the axial direction of said wave guide **7**, an object **11** placed in said axial direction is effectively heated. Where the position of the movable short-circuiting plates **10***a* and **10***b* is adequately adjusted, microwaves are made to run through the heating wave guide **7** in the TM mode and the occurrence of standing waves is suppressed. This prevents the object **11** from being unevenly heated. Moreover, even if the object **11** consists of extremely fine material, it will be scarcely broken due to melting.

As mentioned above, the microwave heating apparatus of this invention enables an object having a small

loss factor or consisting of extemely fine material to be heat treated quickly and efficiently in the heating wave guide.

What we claim is:

1. A microwave heating apparatus comprising:

a microwave oscillator;

a looped wave guide circuit for circulating microwaves received from the microwave oscillator in the same direction, said circuit including:

a directional coupler comprised of a main wave guide connected at one end to the microwave oscillator and at the other end to a dummy load, and a supplementary wave guide coupled to and receiving energy from said main wave guide; and

a heating wave guide coupled to said supplementary wave guide for transmitting in the TM mode the microwaves received from the microwave oscillator via said directional coupler; and

means for bringing the microwaves circulating through the looped wave guide circuit in-phase with the microwaves supplied to said looped wave guide circuit from the microwave oscillator, thereby efficiently heating an object introduced in the axial direction of the heating wave guide.

2. The microwave heating apparatus according to claim **1** wherein the heating wave guide is a circular type wave guide having a movable short-circuiting plate provided at both ends thereof.

3. The microwave heating apparatus according to claim **1** wherein said looped wave guide circuit includes first and second connection wave guides coupling said heating wave guide to said supplementary wave guide.

4. The microwave heating apparatus according to claim **3** wherein said connection wave guides are respectively connected at either end of said supplementary wave guide at right angles to the axis of said supplementary wave guide.

5. The microwave heating apparatus according to claim **4** wherein said connection wave guides are connected to said heating wave guide at right angles thereto.

6. The microwave heating apparatus according to claim **3** wherein said connection wave guides are connected to said supplementary wave guide and to said heating wave guide at right angles thereto.

7. The microwave heating apparatus according to claim **1** wherein said means for bringing the microwaves in-phase comprises a phase shifter located in said looped wave guide circuit.

8. The microwave heating apparatus according to claim **3** wherein said means for bringing the microwaves in-phase comprises a phase shifter located in one of said connection wave guides.

9. The microwave heating apparatus according claim **1** wherein said main wave guide and said supplementary wave guide are attached to each other and are oriented in the same direction, and wherein said directional coupler includes at least one hole in the walls of said main and supplementary wave guides for coupling energy from said main wave guide to said supplementary wave guide.

* * * * *