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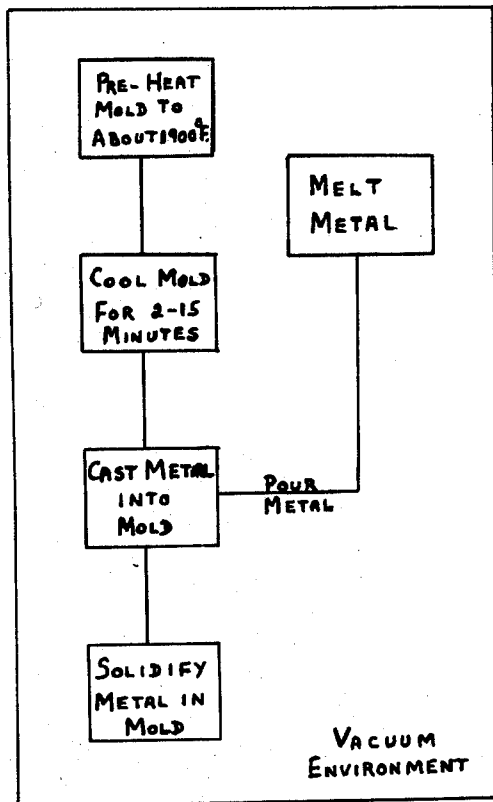
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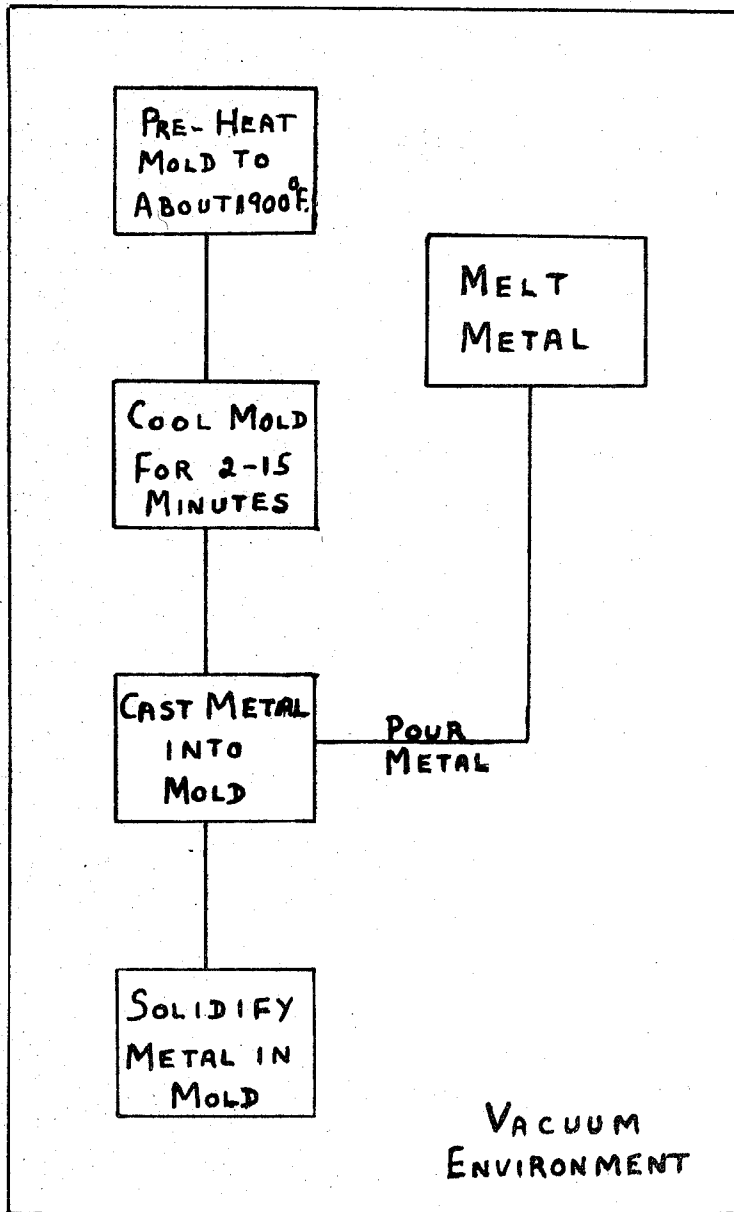
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[54] **CASTING PROCESS INVOLVING COOLING OF A SHELL MOLD PRIOR TO CASTING METAL THEREIN**  
 4 Claims, 1 Drawing Fig.

[52] U.S. Cl. .... 164/65,  
 164/121, 164/122  
 [51] Int. Cl. .... B22d 27/16  
 [50] Field of Search ..... 164/121,  
 122, 125, 65, 61; 75/171

**ABSTRACT:** Method of precision casting of high temperature, nickel-base alloys in ceramic shell molds wherein, immediately prior to casting, a preheated shell mold is permitted to cool to provide a condition wherein there are substantial temperature differentials throughout the shell mold. Substantially enhanced characteristics are obtained in the resultant casting.





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## CASTING PROCESS INVOLVING COOLING OF A SHELL MOLD PRIOR TO CASTING METAL THEREIN

The present invention is concerned with casting of alloys and, more particularly, with the casting of nickel-base, chromium-containing super alloys in ceramic shell molds. When parts, subjected in use to high stress at high temperatures, must be made of nickel-base alloys containing chromium and elements adapted to provide hardening by the mechanisms of solid solution strengthening, carbide-hardening and gamma prime precipitation and such alloys are not adapted to be forged to shape, it is most often convenient to cast such alloys substantially to shape by precision casting techniques using ceramic shell molds. In this way, expensive grinding and machining operations on cast parts are minimized. In general, a shell mold is a mold having a coherent ceramic body adapted to contain molten metal within walls having thicknesses between about one-eighth to about one-half inch. Shell molds are usually made by repeatedly dipping a fugitive model in a ceramic slurry containing a binder material, stuccoing the dipped model with particulate refractory between dips and, after sufficient thickness, e.g. about three-eighths inch, of dipped coatings has been obtained, causing the fugitive model to be removed from the built-up mold. As an example, one can produce a shell mold by coating a wax model of a turbine blade with refractory such as zircon or alumina. As indicated above, the coating is provided by first dipping the model into a slurry of very finely-divided refractory, removing the slurry coated model from the dipping bath and stuccoing the slurry coated model with particulate refractory having a particle size substantially in excess of the particle size of the refractory in the slurry. This dipping and stuccoing process is repeated until the required thickness of approximately three-eighths inch is obtained. After the coating on the model is dry and a temporary bond is obtained, the model can be removed by dissolution, melting, burning or the like. The shell mold is then matured and provided with a ceramic bond by firing at an elevated temperature; for example, at about 1,600 to 2,000° F. By now, such shell molds are common items used in the precision casting industry although, in view of their peculiar nature, they are not generally considered to be articles of commerce. Particular ways of manufacturing shell molds are set forth and described in the literature particularly in, for example, U.S. Pat. Nos. 2,932,864; 3,132,388 and 2,961,751.

In physical form, shell molds, the manufacture of which is described generally in the preceding paragraph, include not only a cavity in the shape of the article to be molded but also connecting cavities in the shapes of feeders, risers, sprues, pouring basins and the like such that all of the features required by proper casting technique are incorporated in the ceramic shell mold. Quite often, but not necessarily, the shell mold is employed in vacuum casting. It is well known that the normal atmosphere can contaminate most metals when the metal is in the molten state. With common metals such as steel, it is quite usual to at least partially protect the molten metal from atmospheric contamination by melting and pouring under a slag cover. When alloys contain even relatively small amounts of elements, such as titanium, aluminum, zirconium, boron and the like, it is highly advantageous to melt and cast such alloys in vacuum. Again, by now, vacuum melting and casting of alloys sensitive to atmospheric contamination is well known in the art. Further, it is, of course, well known in the art to vacuum cast such alloys into ceramic shell molds of the type described hereinbefore.

Certain nickel-base alloys containing chromium (primarily for oxidation resistance) and other elements designed to provide hardening by means of solid solution strengthening, carbide strengthening and gamma prime precipitation are especially adapted to be cast in vacuum. Many of such alloys are not forgeable except in an extremely limited way and are particularly adapted to be employed in gas turbine structures, e.g. hot zone blades where the conditions of use involve exposure to high stress at elevated temperatures. When metals are subjected to stress below their yield point especially at elevated

temperatures, a phenomenon termed "creep" occurs. Creep is generally considered to be an irreversible deformation, the magnitude of which deformation is dependent in part upon time and in part upon temperature and stress. Eventually, creep will cause failure either by causing the metal part to extend beyond limits of tolerance or, in drastic cases, to fracture. Generally speaking, the higher the temperature of use, the more severe is the creep problem assuming a constant applied stress. Conversely, generally speaking, the greater the stress, the more severe is the creep problem assuming a constant temperature. The resistance of a metal to creep at various temperatures is not usually uniformly high or low. It is not only possible but usual for a metal part to exhibit good creep resistance at 1,800° F. and relatively poor creep resistance at 1,400° F. Conversely, a part made of identical metal chemistry but somewhat different prior thermal history may have relatively poor creep resistance at 1,800° F. and relatively good creep resistance at 1,800° F. and relatively good creep resistance at 1,400° F.

It is known that many factors are involved in the actual performance of metal structures under creep inducing conditions. The present invention is concerned with one of these factors, to wit: the solidification rate and the rate of cooling of precision cast metal, cast into ceramic shell molds such as described hereinbefore. The solidification rate and the rate of cooling are primarily affected by the pouring temperature of the metal and the initial mold temperature at the start of casting. It is known that with many nickel-base alloys of the kind in question, if relatively slow cooling rates are used by providing an initial high mold temperature, good 1,400° F. creep rupture properties and ductility can be provided. Under such casting conditions the creep resistance properties at 1,800° F. of the cast metal are relatively low. Conversely, if a low mold temperature is used to provide extremely rapid cooling, extremely good creep properties can be provided for use at 1,800° F. but only at a sacrifice of properties at 1,400° F., such as ductility. If it were possible to design turbine engines to operate uniformly at a single high temperature the aforescribed casting variances would provide no difficulty. In practice, however, the high temperature section of a jet engine does not operate at a single temperature. The temperature of a single turbine blade in the hot section of a jet engine can vary in different spots across its cross section and in different spots along its length. It is not impossible that a single practical operating turbine blade would involve in different areas thereof temperatures ranging from 1,400 to 1,800° F. at any given moment of operation. Furthermore, during starts and stops the temperatures in the hot section of a turbine engine can vary over the range of from ambient atmospheric temperatures to up to 2,000° F. For these reasons it is important to provide cast structures having optimum properties over a reasonably wide range of elevated temperatures. The present invention is concerned with the solution of this problem which, as far as I am aware, has not heretofore been solved in a satisfactory manner on a commercial scale.

It is an object of the present invention to provide a novel process for the production of structures subjected in use to stress at a range of elevated temperatures.

It is another object of the present invention to provide structures for use under stress over a range of elevated temperatures.

Other objects and advantages of the present invention will become apparent from the following description taken in conjunction with the drawing which depicts the process of the invention in schematic form.

Generally speaking, the present invention contemplates the process of casting and the product produced thereby wherein an alloy (metal), selected from the group of certain nickel-base alloys specified hereinafter, in molten form at a temperature of about 200° F. above the freezing point thereof is poured into a ceramic shell mold characterized just prior to the start of pouring by having different temperatures in different areas in and on the mold with the spread of the tem-

peratures being in the range of about 100° to 350° in Fahrenheit units, and the poured metal is thereafter allowed to cool and solidify in said shell mold. The maximum and minimum of the aforementioned temperatures both are between the limits of about 400° to about 1200° in Fahrenheit units below the freezing point of the metal. Advantageously the maximum of said temperature spread is about 800° in Fahrenheit units below the freezing point of the metal and the minimum is about 1,100° in Fahrenheit units below the freezing point of the metal. For purposes of this specification and claims, the freezing point of an alloy (metal) shall be considered to be the liquidus of the particular alloy composition employed.

The nickel-base alloys particularly adapted to be employed in the process of the present invention are nickel-base, chromium-containing alloys having in the solid state a gamma matrix, a gamma prime precipitate dispersed throughout the matrix upon initial solidification of the alloy from the molten state, elements in solid solution to strengthen said gamma matrix and carbide particles dispersed throughout the alloy body. Generally speaking, such alloys will contain at least about 5 percent of an element selected from the group consisting of titanium and aluminum or both, at least 2 percent of an element selected from the group of molybdenum, tungsten, columbium, or tantalum, at least about 0.02 percent carbon and, advantageously, small amounts of boron and zirconium, for example up to about 0.02 percent of boron and up to about 0.3 percent of zirconium. Advantageously, such alloys can contain up to about 20 percent cobalt and may contain amounts of iron, manganese, silicon and other incidental elements which do not affect the basic characteristics of the alloys. As is well known to alloy developers, the composition of such alloys will be balanced so as to avoid the formation of embrittling phases during exposure to elevated temperatures. A typical alloy which is particularly adapted to be treated by the process of the present invention is that alloy known in commerce as B-1900 which has a nominal composition as set forth in table I.

TABLE I

Element:	Percent by weight
Chromium.....	8. 0
Molybdenum.....	6. 0
Titanium.....	1. 0
Aluminum.....	6. 0
Boron.....	0. 015
Zirconium.....	0. 10
Cobalt.....	10. 0
Carbon.....	0. 10
Tantalum.....	4. 0
Nickel.....	Balance

The nominal compositions of other alloys which can be employed in the process of the present invention are set forth in table II.

TABLE II

Alloy	Cr	Mo	Cb	Ti	Al	B	Zr	Co	C	Ni	W	Ta	Fe	V
INCONEL <sup>1</sup> alloy 713C.....	12.5	4.2	2.0	8	6.1	0.012	0.10	.....	0.12	Balance.....	.....	.....	.....	.....
MAR M <sup>2</sup> alloy 200.....	9	.....	1	2	5	0.015	0.05	10	0.15	.....do.....	12.5	.....	.....	.....
IN 100.....	10.0	3	.....	4.7	5.5	0.014	0.06	15	0.18	.....do.....	.....	.....	.....	.....
MAR M <sup>2</sup> alloy 246.....	9.0	2.5	.....	1.5	5.5	0.015	0.05	10	0.15	.....do.....	10	1.5	.....	.....

<sup>1</sup> INCONEL is a trademark of The International Nickel Company Inc.

<sup>2</sup> MAR M is a trademark of Martin Marietta Corporation. The alloys sold under this trademark were formerly sold under the trademark S-M.

From the foregoing tables and description it is to be observed that alloys having compositions within the ranges set forth in table III are adapted to be used in the present invention.

TABLE III

Element:	Nickel-base alloys (percent by weight)
Chromium.....	8-18
Cobalt.....	0-20
Tungsten.....	0-13.5
Molybdenum.....	0-12
Aluminum.....	4-7
Titanium.....	0-6
Aluminum plus titanium.....	6-11
Carbon.....	0.02-0.3
Boron.....	0-0.02
Zirconium.....	0-0.25
Vanadium.....	0-2
Iron.....	0-5
Tantalum.....	0-6
Columbium.....	0-6
Nickel.....	<sup>1</sup> Balance

<sup>1</sup> Together with impurities and incidental elements which do not adversely affect the utility of the alloys.

When alloys within the range of composition set forth in table III are cooled from the molten state, carbide phases are initially formed in the solid metal followed by gamma prime precipitate. Many of the alloys adapted to be used in the process of the present invention are not amenable to be solution-treated and aged to redistribute and/or reform carbide and gamma prime phases.

In carrying out the process of the present invention one of the easiest ways to achieve the required temperature profile of the shell mold, as described hereinbefore, is to initially heat the mold to a temperature of 1,900° F. and then cool the mold, advantageously in vacuum, for about 2 to about 15 minutes or more before casting metal therein. If the cooling is accomplished primarily by radiation, it is thought that the inner walls of the mold should cool slower than the outer walls because the heat sinks to which the inner walls will be radiating (each other) will be much higher in temperature than the sinks to which the outer walls radiate. The same should essentially be true if the shell mold is cooled in air provided one avoids cooling the mold by pumping cooling air through the mold cavity. In practice, however, the temperature profile of the cooled shell mold does not seem to be simply that the inner, metal-contacting walls of the shell mold are 200° to 300° in Fahrenheit units hotter than the outer walls of the mold with intermediate temperatures therebetween. Apparently the cooling process is more complex than what would be thought to be the case. The complexity of the cooling process introduces temperature variations throughout the whole mold whereby certain areas are hotter by up to about 300° in Fahrenheit units than the coolest areas of the mold. When metal such as B-1900 is cast using a pouring temperature of about 200° F. above the freezing point into the mold cooled from 1,900° F. to provide the aforementioned thermal

gradient throughout the mold, one obtains an excellent combination of stress rupture and creep rupture life at 1,800 and 1,400° F. Advantageously, when cooling by radiation in a vacuum from an initial mold temperature at 1,900° F., the

cooling period is about 3 to about 10 minutes, for example about 5 to about 9 minutes, to optimize all properties. It is to be recognized that the present invention contemplates casting metal into a shell mold having the defined temperature differentials no matter how such a condition is created. The sequence of practical steps of the process of the present invention involving cooling for about 2 to about 15 minutes is depicted in schematic form on the drawing.

In order to give those skilled in the art a greater appreciation of the advantages of the invention, the following examples are given:

Example I

Alloy corresponding to the chemistry set forth in table I, which is known in the industry as B-1900 was melted under vacuum and held at a temperature of approximately 200° in Fahrenheit units above the freezing point as measured by an uncorrected optical pyrometer. At the same time a shell mold, as described hereinbefore, containing a plurality of cavities conforming to the shape of stress-rupture specimens was heated to 1,900° F. and allowed to cool for about seven minutes to provide a differential of about 200° to 300° in Fahrenheit units within the body of the mold. The metal is then poured into the mold while under vacuum.

Table IV contains data comparing mechanical characteristics of metal of the same alloy content (A) as cast into a mold maintained at about 1,900° F., (B) as cast into a mold maintained at about 1,600° F. and (C) as cast into a mold under the conditions described in example I.

TABLE IV

	A (Mold at 1,900° F.)	B (Mold at 1,600° F.)	C Example I
Life-to-rupture under stress of 29,000 p.s.i. at 1,800° F. (Hours)...	25-35	55	50-60
Life-to-rupture under stress of 94,000 p.s.i. at 1,400° F. (Hours)...	75	15-25	70-100

NOTE.—p.s.i.=pounds per square inch.

Table IV shows that, by using the process of the present invention, one can provide structures made from alloy B-1900 having an excellent combination of high temperature mechanical characteristics, the measured characteristics being essentially equal if not superior to the optimum stress-rupture characteristics obtainable at either 1,400° F. or 1,800° F. using prior molding techniques A or B.

Example II

An alloy having the chemistry of that alloy identified in table II as MAR M alloy 246 was melted and cast in exactly the same fashion as was described in Example I except that the mold was allowed to cool for about 10 minutes. Table V parallels table IV in showing the advantageous results obtainable with the process of the present invention.

TABLE V

	A (Mold at 1,900° F.)	B (Mold at 1,600° F.)	C Example I
Life-to-rupture at 1,800° F. under a stress of 32,000 p.s.i. (hours).....	27	50	53
Life-to-rupture at 1,400° F. under a stress of 100,000 p.s.i. (hours)....	79	35	141

Equally impressive results are obtained with other alloy compositions of similar nature such as those set forth in table II and within the compositional limits set forth in table III. By means of the present invention one can produce structures having a remarkable combination of high temperature characteristics making the structures particularly applicable for use in the hot sections of gas turbine engines. When the present invention is used in conjunction with state of the art techniques relating to mold preparation, melting and casting, one can expect to achieve overall superior properties in alloy structures which are usable at temperatures from room temperature to the highest temperature limit of the alloy in question. Structures producible in accordance with the present invention include gas turbine blades, vanes, integrally cast turbine wheels, and other applications of high temperature alloys.

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## Example III

As a final example of the utility and unobviousness of the present invention a relatively newly developed high temperature nickel-base chromium-containing alloy was cast into test bars using a ceramic shell mold cooled-back from 1,900° F. for various amounts of time.

TABLE VI

Time of cooling back (minutes)	Stress rupture data 18-27.5 <sup>1</sup>		Hot Tensile Data at 1,600° F.		
	Life (hours)	Reduction of area (percent)	U.T.S. (K s.i.)	Y.S. 0.2% offset (K s.i.)	Reduction of area (percent)
2	24.5	12.6	102.8	77.9	10.5
4	23.2	16.4	102.6	78.0	13.0
6	26.4	10.8	103.2	74.7	15.5
8	25.0	13.0	103.2	75.9	17.3
10	24.7	18.2	101.0	81.3	22.7

<sup>1</sup> Stress rupture specimens subjected to a load of 27.5 K s.i. (27,500 p.s.i.) at 1,800° F.

Table VI shows that the reduction-of-area of the relatively newly developed alloy in hot tensile test at 1,600° F. is greatly improved, e.g. over 100 percent improvement, without detriment to other characteristics significant from an engineering standpoint. At least one major jet engine manufacturer considers the reduction-of-area during hot tensile testing to be a highly significant factor in determining the suitability of an alloy or alloy structure for hot stage jet engine service. Table VI shows that hot tensile reduction-of-area can be raised from 10.5 percent up to 22.7 percent and even higher for this particular alloy by means of the present invention without significantly varying the stress rupture life and accompanying reduction-of-area at 1,800° F. under a load of 27.5 k.s.i. from the average values of 24.8 hours and 14.2 percent, respectively, and without significantly varying the Ultimate Tensile Strength (U.T.S.) and 0.2 percent offset Yield Strength (Y.S.) at 1,600° F. from the average values of 102.6 k.s.i. and 77.6 k.s.i., respectively.

While the present invention has been described in conjunction with advantageous embodiments, those skilled in the art will recognize that modifications and variations may be resorted to without departing from the spirit and scope of the invention. Such modifications and variations may be resorted to without departing from the spirit and scope of the invention. Such modifications and variations are considered to be within the purview and scope of the invention.

I claim:

1. A process of casting nickel-base high temperature alloy, said alloy being adapted to be used under load at temperatures

in the range of about 1,200° F. to 2,000° F. and comprising, as a solid, a matrix gamma phase, a gamma prime phase and a carbide phase, comprising the steps of:

- a. melting said alloy under vacuum;
- b. superheating said alloy to about 200° in Fahrenheit units above the freezing point thereof while maintaining said vacuum to place said alloy in condition for pouring into a

- mold;
  - c. initially preheating a refractory shell mold to about 1,900° F. in vacuum;
  - d. causing said initially preheated refractory shell mold to cool by radiation in said vacuum from about 1,900° F. for about 2 to about 15 minutes to provide a refractory shell mold, characterized by having a diversity of temperatures at diverse locations therein and thereon with a spread of about 100° to 350° in Fahrenheit units between the maximum and the minimum of said temperatures, said maximum and minimum of said temperatures being between about 400° and 1,200° in Fahrenheit units below the freezing point of said alloy;
  - e. immediately after said cooling, casting said superheated alloy into said cooled shell mold while still maintaining vacuum thereon; and
  - f. thereafter maintaining said vacuum conditions until said alloy has frozen in said shell mold whereby said alloy thus cast exhibits maximized mechanical characteristics in both the lower and the higher portions of said temperature range of about 1,200° F. to 2,000° F.
2. A process as in claim 1 wherein the refractory shell mold is made of zircon or alumina as is made by the lost wax process.
  3. A process as in claim 1 wherein the refractory shell mold is cooled from about 3 to about 10 minutes.
  4. A process as in claim 1 wherein the refractory shell mold encloses a volume in the shape of a gas turbine blade.

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UNITED STATES PATENT OFFICE  
CERTIFICATE OF CORRECTION

Patent No. 3,552,479 Dated January 5, 1971

Inventor(s) John Hockin

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, lines 18-19, "1800°F. and relatively good creep resistance at" was incorrectly restated and should be cancelled;

Column 6, in Table V - last column in table under "C" - "Example I" should be -- Example II --;

Column 7, lines 44-46, "Such modifications and variations may be resorted to without departing from the spirit and scope of the invention." was incorrectly stated and partly repeated and should be cancelled.

Signed and sealed this 20th day of April 1971.

(SEAL)  
Attest:

EDWARD M. FLETCHER, JR.  
Attesting Officer

WILLIAM E. SCHUYLER,  
Commissioner of Patent