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**US - A - 4 182 312**

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EP **0040165 B1**

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## Description

La présente invention a pour objet un procédé de réalisation d'une prothèse.

Le type de prothèse dont il s'agit comprend par exemple les couronnes utilisées en art dentaire pour le remplacement de dents. La réalisation d'une couronne nécessite les diverses opérations suivantes, illustrées par les figures 1 à 5 du dessin schématique annexé:

- Taille de la dent à remplacer pour obtenir un moignon 1 de forme tronconique comme montré à la figure 1 du dessin schématique annexé.
- Prise de l'empreinte du moignon à l'aide d'une pâte élastomère en vue d'obtenir un moule 2 dont la partie creuse 3 a un profil complémentaire de celui du moignon, comme montré à la figure 2.
- Coulée de plâtre 4 dans le moule pour obtenir la reproduction du moignon, comme montré à la figure 3.
- Réalisation de la couronne 5 en cire en tenant compte des dents adjacentes et antagonistes, comme montré à la figure 4.
- Mise en place de la couronne 5 dans un cylindre de revêtement 6, comme montré à la figure 5.
- Chauffage de l'ensemble pour la réalisation de la sublimation de la cire.
- Injection de métal fondu dans la cavité précédemment occupée par la cire.
- Démoulage puis polissage de la couronne métallique ainsi obtenue et,
- Pose en bouche.

Il s'agit d'une technique très ancienne présentant de nombreux inconvénients et notamment une mise en œuvre longue et fastidieuse nécessitant, d'une part, l'intervention d'un chirurgien-dentiste et, d'autre part, d'un mécanicien, conduisant à des délais de réalisation assez importants.

Il faut également noter une relative imprécision due au grand nombre d'étapes, un inconfort du patient, et des possibilités d'allergie chez celui-ci, des problèmes psychologiques chez les enfants; et au niveau de la réalisation de la prothèse proprement dite une restriction des matériaux utilisés qui doivent être fluides ou malléables à des températures facilement accessibles, un coût élevé du matériel utilisé qui est constitué notamment par un four, une fronde et une sableuse, et une imprécision due au défaut de maîtrise de la dilatation des matériaux.

D'autres pièces prothétiques posent également des problèmes de réalisation tels que celles utilisées en ostéosynthèse et nécessitant l'utilisation de la méthode dite de »l'empreinte sanglante», c'est-à-dire correspondant à une intervention chirurgicale pour la seule réalisation d'une empreinte directement sur l'os lésé.

Le brevet US 3 861 044 concerne un procédé de réalisation d'une prothèse dentaire et plus

spécialement d'un inlay, consistant à préparer la dent à traiter, à effectuer une saisie optique de la zone de la dent devant recevoir la prothèse par une technique photographique traditionnelle, à transférer les informations fournies par la saisie optique à une machine-outil à commande numérique, à boucher la cavité ménagée dans la dent par de la cire, afin de reconstituer le profil théorique de l'extérieur de la prothèse à obtenir, à réaliser une saisie photographique de la surface extérieure de la cire, à transférer les informations de cette seconde saisie à la machineoutil à commande numérique, puis à usiner la prothèse à partir des deux séries de valeurs résultant des deux saisies optiques, fournies successivement à la machineoutil.

Ce procédé nécessite d'effectuer deux saisies optiques, et d'effectuer un travail dans la bouche du patient préalablement à la seconde saisie. Ce procédé ne peut, compte tenu de l'importance du travail en bouche, s'appliquer qu'à des petites prothèses. En outre, les valeurs résultant des deux saisies étant transférées directement à la machine-outil, il n'est pas possible d'adopter les cotes de la prothèse aux nombreux paramètres imposés par l'environnement de celle-ci, afin qu'elle soit posée dans les meilleures conditions.

La présente invention vise à fournir un procédé remédiant à ces inconvénients.

Ce procédé consiste à réalisée une empreinte optique de la partie du corps destinée à recevoir la prothèse par une technique d'interférométrie, à réaliser, de façon connue en soi, une conversion analogique numérique ou analogique électrique de l'information obtenue lors de la prise d'empreinte, puis à effectuer un traitement des données obtenues par la prise d'empreinte en adaptant celles-ci à des informations théoriques stockées dans la mémoire du calculateur utilisé pour le traitement, et en tenant compte d'un certain nombre de paramètres, tels que nature des matériaux utilisés, environnement de la prothèse, conditions d'utilisation de celle-ci, en vue de déterminer la forme de la prothèse, puis à fournir, de façon connue en soi, les informations obtenues à une machine-outil à commande numérique réalisant la sculpture de la prothèse.

Ce procédé permet la réalisation entièrement automatique d'une prothèse avec possibilité de conservation de l'empreinte optique. Si ce procédé nécessite un appareillage relativement sophistiqué et onéreux puisque nécessitant un ordinateur et une machine à commande numérique, il présente l'avantage d'une précision très importante dans la réalisation de la prothèse et d'une grande rapidité d'exécution compte tenu de la suppression de toutes les phases intermédiaires des techniques actuelles. Cette suppression des phases intermédiaires et le gain de temps obtenu, permettant un amortissement rapide du matériel, d'autant plus que l'ordinateur mis en œuvre peut être également utilisé à

d'autres fins.

Selon un mode de mise en œuvre, ce procédé consiste à réaliser la prise d'empreinte par la technique d'holographie.

Celle-ci consiste à utiliser une source d'ondes, afin d'obtenir l'empreinte sous forme d'interférence d'ondes. Or, une interférence d'ondes portant en elle-même la notion de distance, en effectuant un hologramme on réalise une empreinte indéformable.

Conformément à une première possibilité, l'onde est recueillie sur une plaque holographique avec en interférence une onde de référence de longueur d'onde connue.

Selon une autre possibilité, l'information est reçue directement sur un convertisseur analogique numérique ou analogique électrique.

Avantageusement, l'empreinte est obtenue par projection sur l'organe à équiper d'une prothèse, d'une onde parfaitement monochromatique de type laser, non traumatisante pour les tissus, d'une puissance de 100 millijoules par exemple.

La prise d'empreinte peut être réalisée sur des organes visibles tels que des moignons de dents dans le cas où la prothèse est une couronne dentaire ou à travers certaines matières telles que peau et tissus pour visualiser des organes sous-jacents, par exemple pour la réalisation de prothèses d'ostéosynthèse, sans avoir à recourir à la technique de l'empreinte sanglante.

A partir de l'hologramme, il est procédé à une conversion analogique numérique, les numéros correspondant aux dimensions de la pièce à partir de laquelle on va travailler. Il est rappelé qu'un convertisseur analogique numérique est un appareil qui, utilisant des données analogiques, par exemple l'intensité des franges d'interférence les transforme en système binaire. Cette transformation exclut toute imprécision car les chiffres ont une valeur absolue et c'est sur eux que les différents programmes agiront.

Un système de multiplexage est couplé au convertisseur qui transmet des informations en code binaire. Ces informations sont transmises par un convertisseur analogique numérique à une machine outil à commande automatique.

A ce stade, la transmission des informations peut être effectuée sous diverses formes connues en informatique telles que bandes perforées, bandes magnétiques ou disques.

Toutes les techniques d'usinage peuvent être utilisées et notamment usinage direct de la pièce par usure ou par découpe de masque.

Comme il ressort de ce qui précède, l'invention apporte une grande amélioration à la technique existante en fournissant un procédé assurant la réalisation automatique d'une prothèse sans nécessiter une prise d'empreinte mécanique, qui est d'une très grande précision, tant au niveau de la prise d'empreinte optique que de la réalisation de la prothèse proprement dite du fait de l'absence d'erreurs au niveau des phases intermédiaires, et du fait de la prise en compte d'un certain nombre de paramètres extérieurs

tels que forme des dents antagonistes et adjacentes, et usure des dents symétriques, dans le cas d'une prothèse dentaire.

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## Revendication

1. Procédé de réalisation d'une prothèse consistant à réaliser une empreinte optique de la partie du corps destinée à recevoir la prothèse par une technique d'interférométrie, à réaliser une conversion analogique numérique ou analogique électrique de l'information obtenue lors de la prise de l'empreinte, puis à effectuer un traitement des données obtenues par la prise d'empreinte en adaptant celles-ci à des informations théoriques stockées dans la mémoire du calculateur utilisé pour le traitement, et en tenant compte d'un certain nombre de paramètres, tels que nature des matériaux utilisés, environnement de la prothèse, conditions d'utilisation de celle-ci, en vue de déterminer la forme de la prothèse, puis à fournir les informations obtenues à une machine-outil à commande numérique réalisant la sculpture de la prothèse.

2. Procédé selon la revendication 1, caractérisé en ce qu'il consiste à réaliser la prise d'empreinte par la technique d'holographie.

3. Procédé selon la revendication 2, caractérisé en ce que l'onde est recueillie sur une plaque holographique avec en interférence une onde de référence de longueur d'onde connue.

4. Procédé selon la revendication 2, caractérisé en ce que l'information est reçue directement sur un convertisseur analogique numérique ou analogique électrique.

## Patentansprüche

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1. Verfahren zum Herstellen einer Prothese mit folgenden Verfahrensschritten:

Anfertigung eines optischen Abdrucks des zum Aufnehmen der Prothese bestimmten Körperteils mittels eines interferometrischen Verfahrens,

Analog-Digitalwandlung oder elektrische Analogwandlung der bei dem Abnehmen des Abdrucks gewonnenen Informationen,

Verarbeiten der durch das Abnehmen des Abdrucks gewonnenen Daten zur Formbestimmung der Prothese, wobei diese Daten an theoretische, in dem Speicher des für die Datenverarbeitung verwendeten Rechners gespeicherte Informationen angepaßt und eine gewisse Anzahl von Parametern berücksichtigt werden (wie z. B. die Art der verwendeten Materialien, die Umgebung der Prothese, deren Benutzungsbedingungen), sowie Zuführen der gewonnenen Informationen zu einer numerisch gesteuerten Werkzeugmaschine für die Herstellung der Prothesenskulptur.

2. Verfahren nach Anspruch 1, dadurch gekennzeichnet, daß der Abdruck durch ein holographisches Verfahren gewonnen wird.

3. Verfahren nach Anspruch 2, dadurch ge-

kennzeichnet, daß die Welle auf einer holographischen Platte unter Interferenz mit einer Referenzwelle bekannter Wellenlänge aufgenommen wird.

4. Verfahren nach Anspruch 2, dadurch gekennzeichnet, daß die Information direkt auf einem Analog-Digitalwandler oder einem elektrischen Analogwandler aufgenommen wird.

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### Claims

1. A process for making a prosthesis, consisting in making an optical impression of the part of the body intended to receive the prosthesis, by an interferometric technique, converting the data obtained in making the impression into their digital or electrical analogue, and then processing the data obtained through the impression, by adapting them to the theoretical data stored in the memory of the computer used for the processing, while taking account of a certain number of parameters such as the nature of the materials to be used, the environment of the prosthesis and the conditions of its utilisation, with a view to determining the shape of the prosthesis, and finally feeding the resulting data into a numerically controlled machine tool which will effect the sculpture of the prosthesis.

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2. A process as in Claim 1, characterised in that it consists in making the impression by the holographic technique.

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3. A process as in Claim 2, characterised in that the wave is recorded on a holographic plate with interference against a reference wave of known wavelength.

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4. A process as in Claim 2, characterised in that the data are recorded directly in a numerical or electrical analogue converter.

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FIG.1

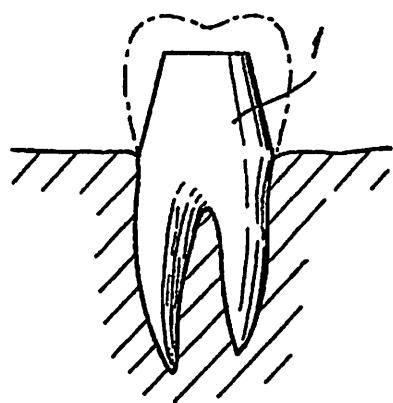


FIG.2

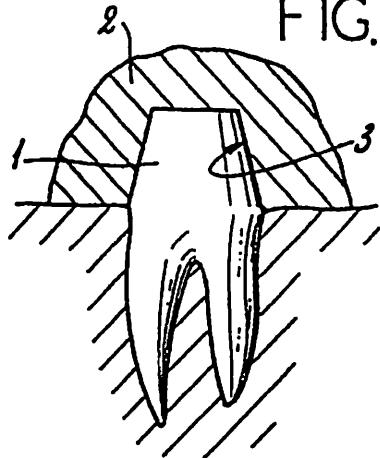


FIG.3

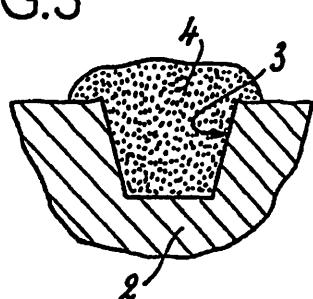


FIG.4

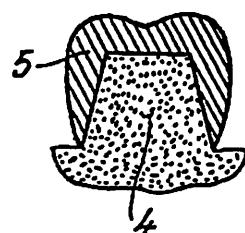
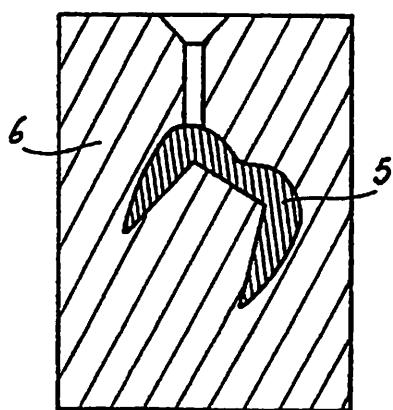


FIG.5



La présente invention a pour objet un procédé de réalisation d'une prothèse.

Le type de prothèse dont il s'agit comprend par exemple les couronnes utilisées en art dentaire pour le remplacement de dents. La réalisation d'une couronne nécessite les diverses opérations suivantes, illustrées par les figures 1 à 5 du dessin schématique annexé :

- Taille de la dent à remplacer pour obtenir un moignon 1 de forme tronconique comme montré à la figure 1 du dessin schématique annexé.

- Prise de l'empreinte du moignon à l'aide d'une pâte élastomère en vue d'obtenir un moule 2 dont la partie creuse 3 a un profil complémentaire de celui du moignon, comme montré à la figure 2.

15 - Coulée de plâtre 4 dans le moule pour obtenir la reproduction du moignon, comme montré à la figure 3.

- Réalisation de la couronne 5 en cire en tenant compte des dents adjacentes et antagonistes, comme montré à la figure 4..

20 - Mise en place de la couronne 5 dans un cylindre de revêtement 6, comme montré à la figure 5.

- Chauffage de l'ensemble pour la réalisation de la sublimation de la cire.

25 - Injection de métal fondu dans la cavité précédemment occupée par la cire.

- Démoulage puis polissage de la couronne métallique ainsi obtenue et,

- Pose en bouche.

Il s'agit d'une technique très ancienne présentant de nombreux inconvénients et notamment une mise en oeuvre longue et fastidieuse nécessitant, d'une part, l'intervention d'un chirurgien-dentiste et, d'autre part, d'un mécanicien, conduisant à des délais de réalisation assez importants.

35 Il faut également noter une relative imprécision due au grand nombre d'étapes, un inconfort du patient, et des possibilités d'allergie chez celui-ci, des problèmes

psychologiques chez les enfants ; et au niveau de la réalisation de la prothèse proprement dite une restriction des matériaux utilisés qui doivent être fluides ou malléables à des températures facilement accessibles,

5 un coût élevé du matériel utilisé qui est constitué notamment par un four, une fronde et une sableuse, et une imprécision due au défaut de maîtrise de la dilatation des matériaux.

D'autres pièces prothétiques posent également des  
10 problèmes de réalisation tels que celles utilisées en ostéosynthèse et nécessitant l'utilisation de la méthode dite de "l'empreinte sanglante", c'est-à-dire correspondant à une intervention chirurgicale pour la seule réalisation d'une empreinte directement sur l'os lésé.

15 La présente invention vise à fournir un procédé palliant les lacunes de la technique existante.

A cet effet, ce procédé consiste à réaliser une empreinte optique de la partie du corps destinée à recevoir la prothèse, à réaliser une conversion analogique numérique  
20 ou analogique électrique de l'information obtenue lors de la prise de l'empreinte, à effectuer un traitement des données tenant compte des caractéristiques de la prothèse à obtenir et déterminant la forme de celle-ci, qui est obtenue par sculpture à l'aide d'une machine outil à  
25 commande numérique.

Ce procédé permet la réalisation entièrement automatique d'une prothèse avec possibilité de conservation de l'empreinte optique. Si ce procédé nécessite un appareillage relativement sophistiqué et onéreux puisque nécessitant  
30 un ordinateur et une machine à commande numérique, il présente l'avantage d'une précision très importante dans la réalisation de la prothèse et d'une grande rapidité d'exécution compte tenu de la suppression de toutes les phases intermédiaires des techniques actuelles. Cette  
35 suppression des phases intermédiaires et le gain de temps obtenu, permettant un amortissement rapide du matériel, d'autant plus que l'ordinateur mis en oeuvre peut être

également utilisé à d'autres fins.

Selon un mode de mise en œuvre, ce procédé consiste à réaliser la prise d'empreinte par la technique d'holographie.

5 Celle-ci consiste à utiliser une source d'ondes, afin d'obtenir l'empreinte sous forme d'interférence d'ondes. Or, une interférence d'ondes portant en elle-même la notion de distance, en effectuant un hologramme on réalise une empreinte indéformable.

10 Conformément à une première possibilité, l'onde est recueillie sur une plaque holographique avec en interférence une onde de référence de longueur d'onde connue.

15 Selon une autre possibilité, l'information est reçue directement sur un convertisseur analogique numérique ou analogique électrique.

Avantageusement, l'empreinte est obtenue par projection sur l'organe à équiper d'une prothèse, d'une onde parfaitement monochromatique de type laser, non traumatisante pour les tissus, d'une puissance de 100 millijoules  
20 par exemple.

La prise d'empreinte peut être réalisée sur des organes visibles tels que des moignons de dents dans le cas où la prothèse est une couronne dentaire ou à travers certaines matières telles que peau et tissus pour  
25 visualiser des organes sous-jacents, par exemple pour la réalisation de prothèses d'ostéosynthèse, sans avoir à recourir à la technique de l'empreinte sanglante.

A partir de l'hologramme, il est procédé à une conversion analogique numérique, les numéros correspondant  
30 aux dimensions de la pièce à partir de laquelle on va travailler. Il est rappelé qu'un convertisseur analogique numérique est un appareil qui, utilisant des données analogiques, par exemple l'intensité des franges d'interférence les transforme en système binaire. Cette transformation exclut toute imprécision car les chiffres ont une valeur absolue et c'est sur eux que les différents programmes agiront.

Un système de multiplexage est couplé au convertisseur qui transmet des informations en code binaire. Ces informations sont transmises par un convertisseur analogique numérique à une machine outil à commande automatique.

5 A ce stade, la transmission des informations peut être effectuée sous diverses formes connues en informatique telles que bandes perforées, bandes magnétiques ou disques.

Selon une autre caractéristique de l'invention, l'appareil assurant le traitement des données possède une  
10 zone de stockage d'informations théoriques, un programme étant prévu qui assure la détermination de la forme de la prothèse en adaptant les données holographiées aux informations théoriques stockées, et tenant compte d'un certain nombre de paramètres, tels que nature des matériaux  
15 utilisés, environnement de la prothèse et conditions d'utilisation de celle-ci.

La prothèse est donc usinée à la fois à partir de données théoriques, tout en étant adaptée au cas précis étudié. C'est ainsi notamment que la sculpture d'une  
20 couronne dentaire tient compte non seulement de la forme du moignon donnée par l'empreinte, de la dimension de l'espace à occuper, mais aussi de la forme des dents antagonistes et adjacentes et de l'usure des dents symétriques.

25 Les mêmes remarques peuvent être faites pour une prothèse chirurgicale pour laquelle il sera tenu compte par exemple du voisinage artériel.

Toutes les techniques d'usinage peuvent être utilisées et notamment usinage direct de la pièce par usure ou par  
30 découpe de masque .

Comme il ressort de ce qui précède, l'invention apporte une grande amélioration à la technique existante en fournissant un procédé assurant la réalisation automatique d'une prothèse sans nécessiter une prise  
35 d'empreinte mécanique, qui est d'une très grande précision, tant au niveau de la prise d'empreinte optique que de la réalisation de la prothèse proprement dite tenue de

l'absence d'erreurs au niveau des phases intermédiaires.

Comme il va de soi, l'invention ne se limite pas aux seuls modes de mise en oeuvre de ce procédé, décrits ci-dessus à titre d'exemples ; elle en embrasse, au contraire, toutes les variantes de réalisation.

- REVENDICATIONS -

1. - Procédé de réalisation d'une prothèse, caractérisé en ce qu'il consiste à réaliser une empreinte optique de la partie du corps destinée à recevoir la prothèse, à 5 réaliser une conversion analogique numérique ou analogique électrique de l'information obtenue lors de la prise de l'empreinte, à effectuer un traitement des données tenant compte des caractéristiques de la prothèse à obtenir et déterminant la forme de celle-ci, qui est obtenue par 10 sculpture à l'aide d'une machine outil à commande numérique.

2. - Procédé selon la revendication 1, caractérisé en ce qu'il consiste à réaliser la prise d'empreinte par la technique d'holographie.

15 3. - Procédé selon la revendication 2, caractérisé en ce que l'onde est recueillie sur une plaque holographique avec en interférence une onde de référence de longueur d'onde connue.

20 4. - Procédé selon la revendication 2, caractérisé en ce que l'information est reçue directement sur un convertisseur analogique numérique ou analogique électrique.

25 5. - Procédé selon l'une quelconque des revendications 2 à 4, caractérisé en ce que l'empreinte est obtenue par projection sur l'organe à équiper d'une prothèse d'une onde monochromatique de type laser, non traumatisante pour les tissus.

30 6. - Procédé selon l'une quelconque des revendications 1 à 5, caractérisé en ce que l'appareil assurant le traitement des données possède une zone de stockage d'informations théoriques, un programme étant prévu qui assure la détermination de la forme de la prothèse en adaptant les données holographiées aux informations théoriques stockées, et tenant compte d'un certain nombre 35 de paramètres, tels que nature des matériaux utilisés, environnement de la prothèse , conditions d'utilisation de celle-ci, et dernières données scientifiques connues.

- A B R E G E -

Ce procédé consiste à réaliser une empreinte optique de la partie (1) du corps destinée à recevoir la prothèse, à réaliser une conversion analogique numérique ou analogique électrique de l'information obtenue lors de la prise de l'empreinte, à effectuer un traitement des données tenant compte des caractéristiques de la prothèse à obtenir et déterminant la forme de celle-ci, qui est obtenue par sculpture à l'aide d'une machine outil à commande numérique.

Figure 1

FIG.1

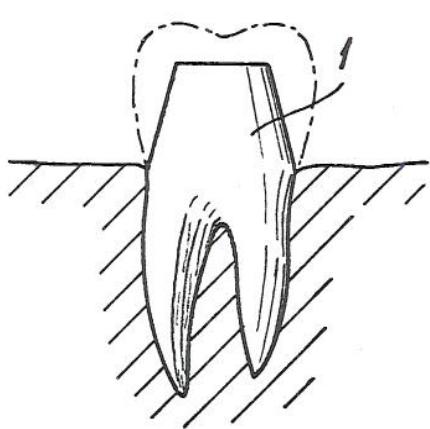


FIG.2

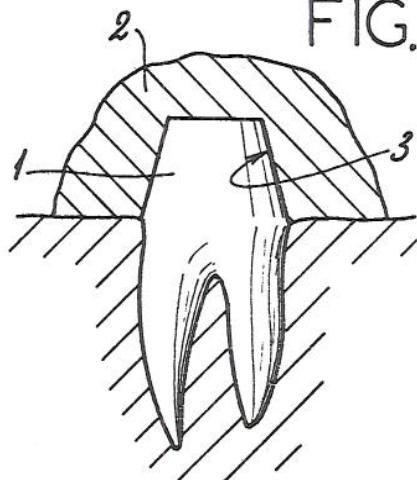


FIG.3

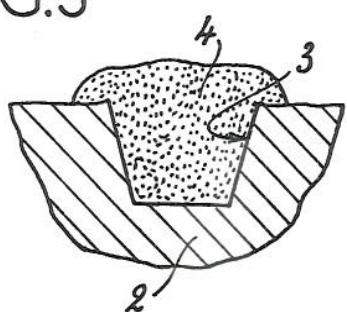


FIG.4

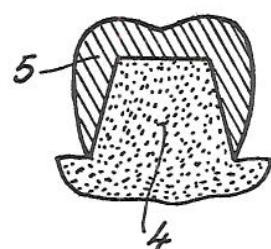
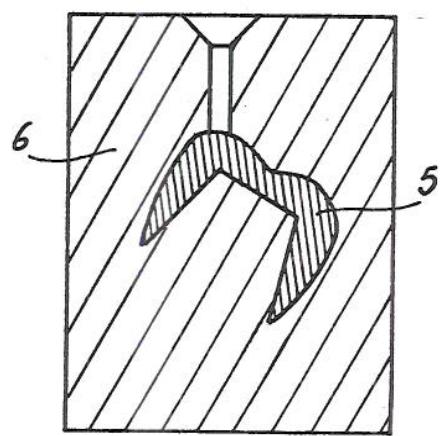


FIG.5



# United States Patent [19]

Duret et al.

[11] Patent Number: 4,663,720

[45] Date of Patent: May 5, 1987

[54] METHOD OF AND APPARATUS FOR  
MAKING A PROSTHESIS, ESPECIALLY A  
DENTAL PROSTHESIS

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Termoz, 2, Place Victor Hugo,  
Grenoble (Isere), both of France

[21] Appl. No.: 673,655

[22] Filed: Nov. 21, 1984

## Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 560,776, Feb. 21, 1984,  
which is a continuation of Ser. No. 262,905, May 12,  
1981, abandoned.

[51] Int. Cl.<sup>4</sup> ..... G06F 15/00; A61C 9/00

[52] U.S. Cl. ..... 364/474; 433/214

[58] Field of Search ..... 364/474, 168, 475;  
356/347, 357, 358; 433/204, 213, 214, 223, 55,  
68, 73

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EP0091876; English Translation; 10-19-83.

Primary Examiner—Jerry Smith

Assistant Examiner—Allen MacDonald

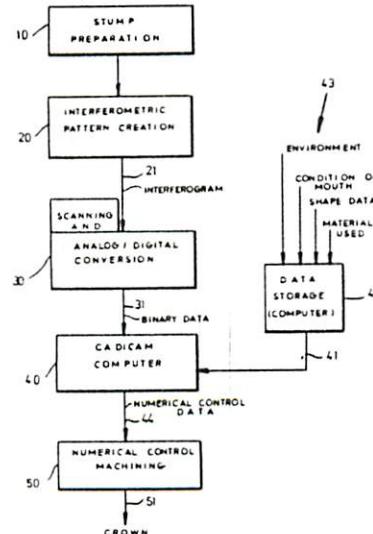
Attorney, Agent, or Firm—Karl F. Ross; Herbert Dubno

[57]

## ABSTRACT

A method of making a dental prosthesis in which data representing standard tooth shapes and sizes, relationships between teeth and adjacent and occlusive teeth and characteristics for securing a prosthesis to a prepared site, and machining instructions for shaping a blank to the configuration of a dental prosthesis for direct implantation are stored in a computer memory. After preparing a site in the mouth of a patient to receive a dental prosthesis, the dental surgeon projects optically a grating upon said site in the mouth of the patient and generates an interference pattern representing a holistic impression of said site and its relationship to adjacent structures. The interference pattern is converted into data along x,y,z coordinates in a cartesian coordinate system representing machining of a blank to fit said site and matching data obtained by comparing the impression with the computer standards are used to select a best-fit shape and size. A machine tool is numerically controlled with the x,y,z coordinate data and x,y,z coordinate data from the match made by the computer and representing the shape and size of the prosthesis to totally and three-dimensionally fabricate said prosthesis in said machine tool.

7 Claims, 21 Drawing Figures



1980, maintenance fees  
and eleven years and six  
months thereafter upon  
ber, and timing of the

FIG.1

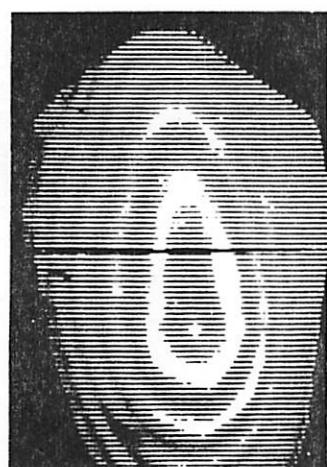


FIG.2

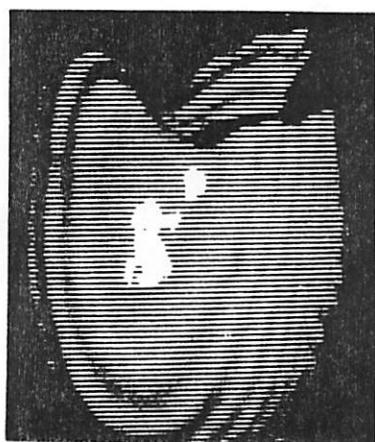


FIG.3

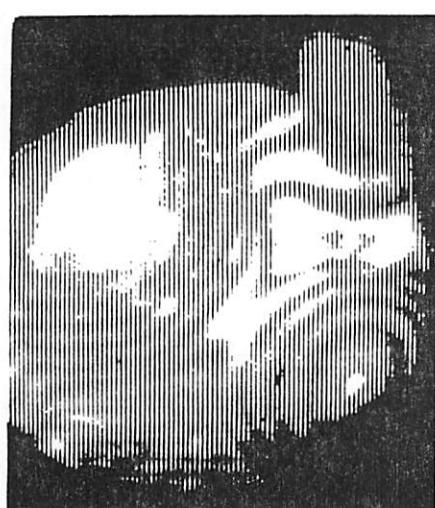


FIG.4



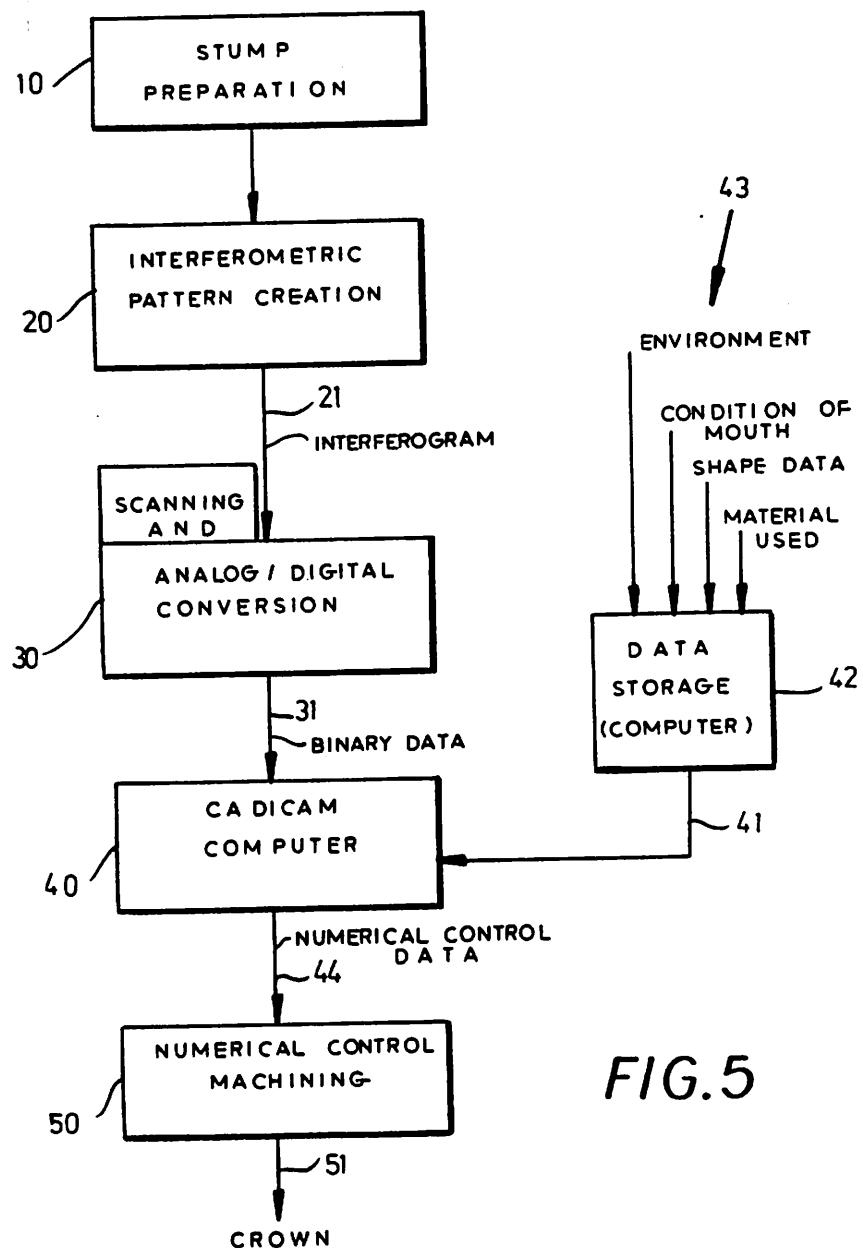
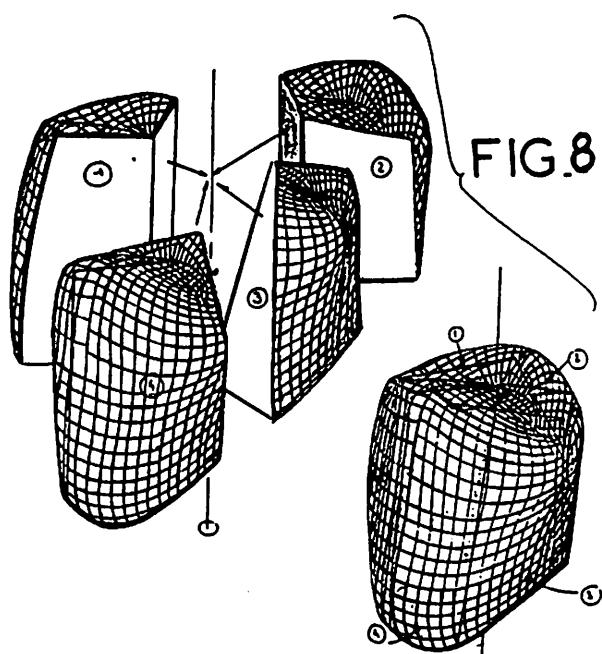
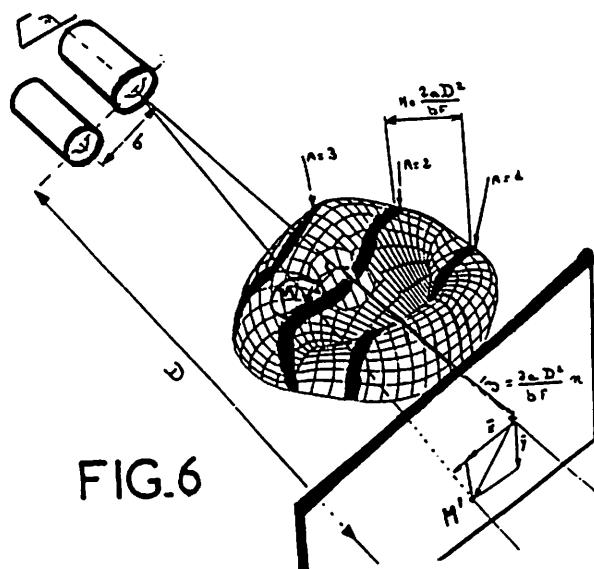


FIG.5



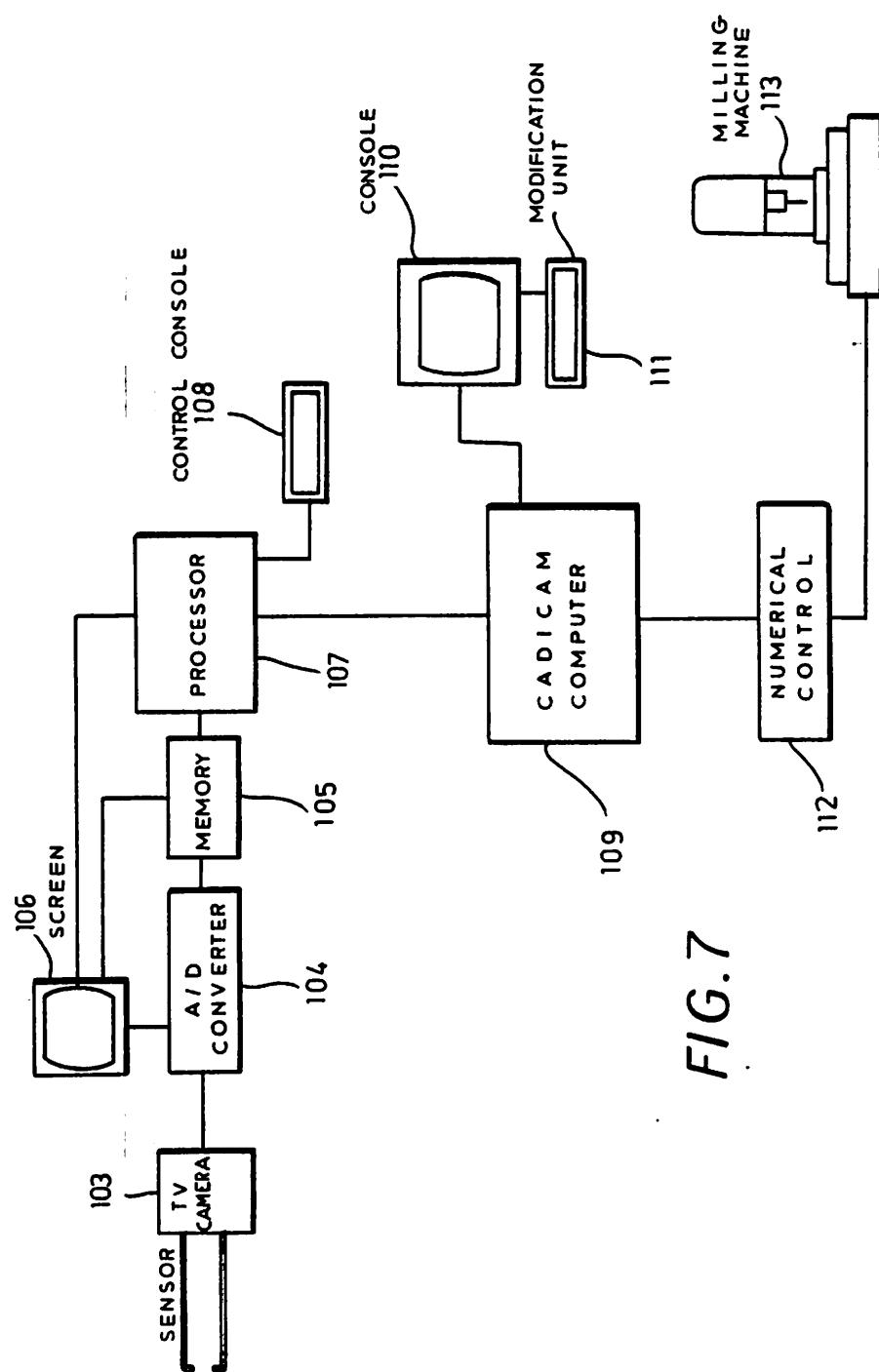


FIG. 7

FIG.9

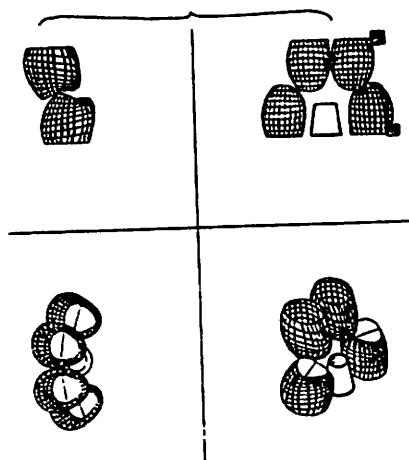


FIG.10

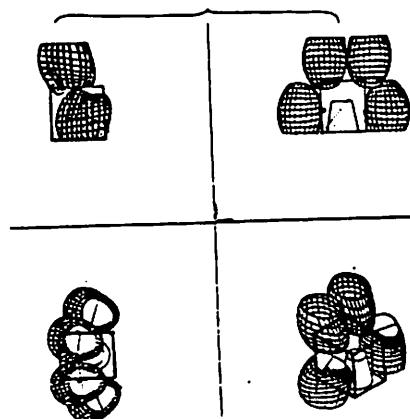


FIG.11

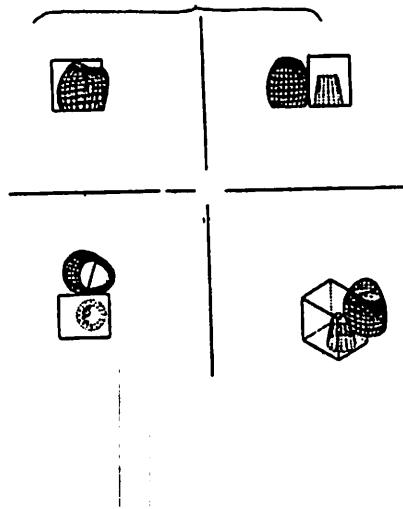


FIG.12

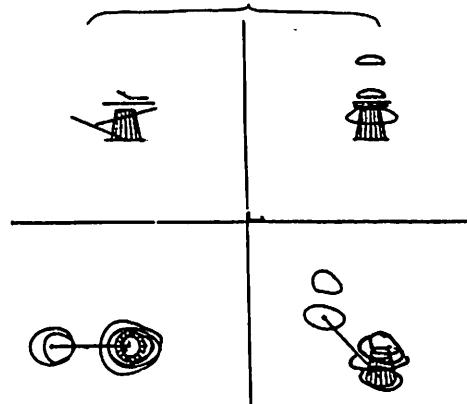
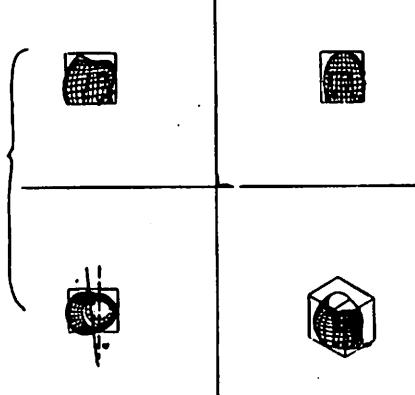


FIG.13



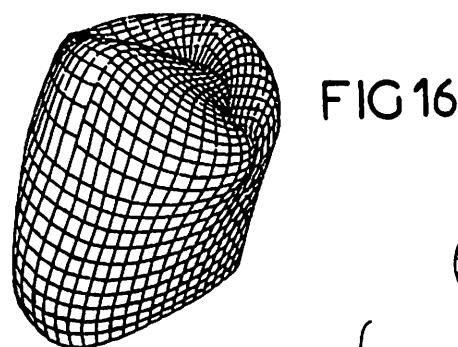
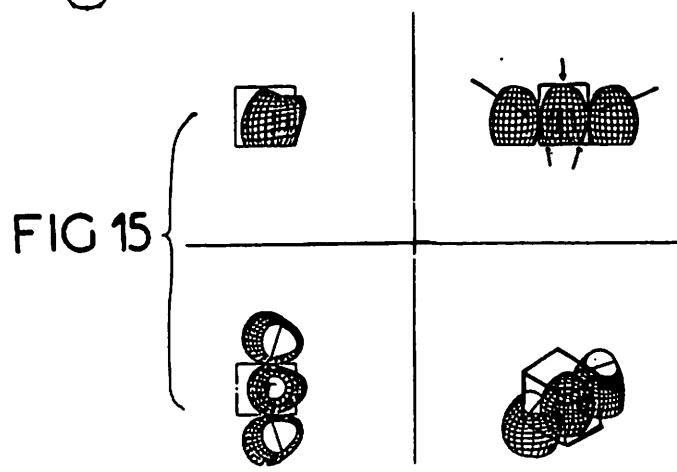
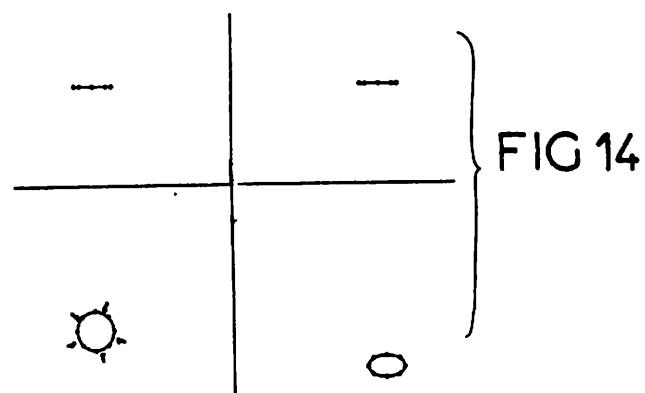


FIG 16

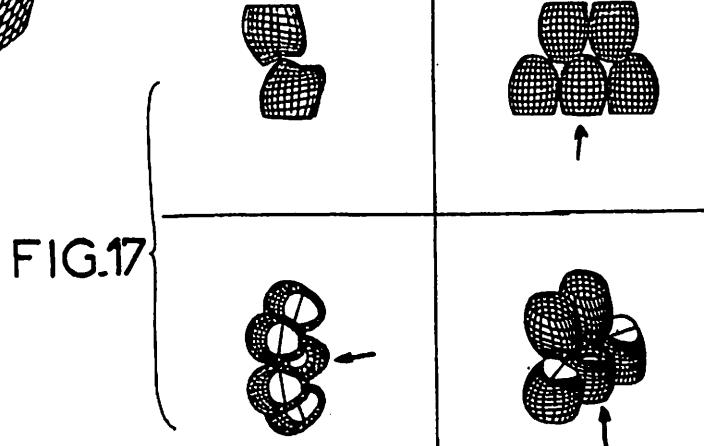


FIG.18

POINT NUMÉRO 1	X = 1.43 286	Y = 0.09 771	Z = -0.32 480
POINT NUMÉRO 2	X = 1.47 239	Y = -0.03 849	Z = -0.32 482
POINT NUMÉRO 3	X = 1.54 654	Y = -0.14 095	Z = -0.32 481
POINT NUMÉRO 4	X = 1.64 498	Y = -0.20 727	Z = -0.32 480
POINT NUMÉRO 5	X = 1.75 752	Y = -0.23 679	Z = -0.32 480
POINT NUMÉRO 6	X = 1.87 423	Y = -0.23 033	Z = -0.32 480
POINT NUMÉRO 7	X = 1.98 552	Y = -0.19 006	Z = -0.32 480
POINT NUMÉRO 8	X = 2.08 213	Y = -0.11 948	Z = -0.32 480
POINT NUMÉRO 9	X = 2.15 522	Y = -0.02 340	Z = -0.32 480
POINT NUMÉRO 10	X = 2.19 637	Y = 0.09 211	Z = -0.32 481
POINT NUMÉRO 11	X = 2.19 768	Y = 0.21 982	Z = -0.32 481
POINT NUMÉRO 12	X = 2.15 205	Y = 0.35 027	Z = -0.32 482
POINT NUMÉRO 13	X = 2.04 011	Y = 0.50 696	Z = -0.32 480
POINT NUMÉRO 14	X = 1.92 823	Y = 0.61 991	Z = -0.32 480
POINT NUMÉRO 15	X = 1.82 272	Y = 0.68 935	Z = -0.32 482
POINT NUMÉRO 16	X = 1.72 603	Y = 0.72 258	Z = -0.32 481
POINT NUMÉRO 17	X = 1.63 922	Y = 0.72 591	Z = -0.32 480
POINT NUMÉRO 18	X = 1.56 338	Y = 0.70 243	Z = -0.32 480
POINT NUMÉRO 19	X = 1.50 010	Y = 0.65 231	Z = -0.32 480
POINT NUMÉRO 20	X = 1.45 169	Y = 0.57 233	Z = -0.32 480
POINT NUMÉRO 21	X = 1.42 147	Y = 0.45 562	Z = -0.32 482
POINT NUMÉRO 22	X = 1.41 385	Y = 0.29549	Z = -0.32 480

FIG.19

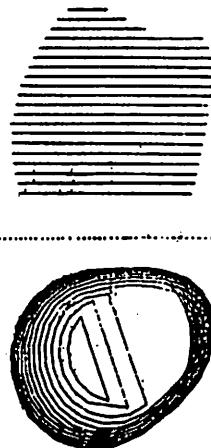
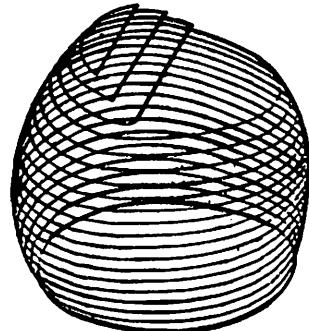
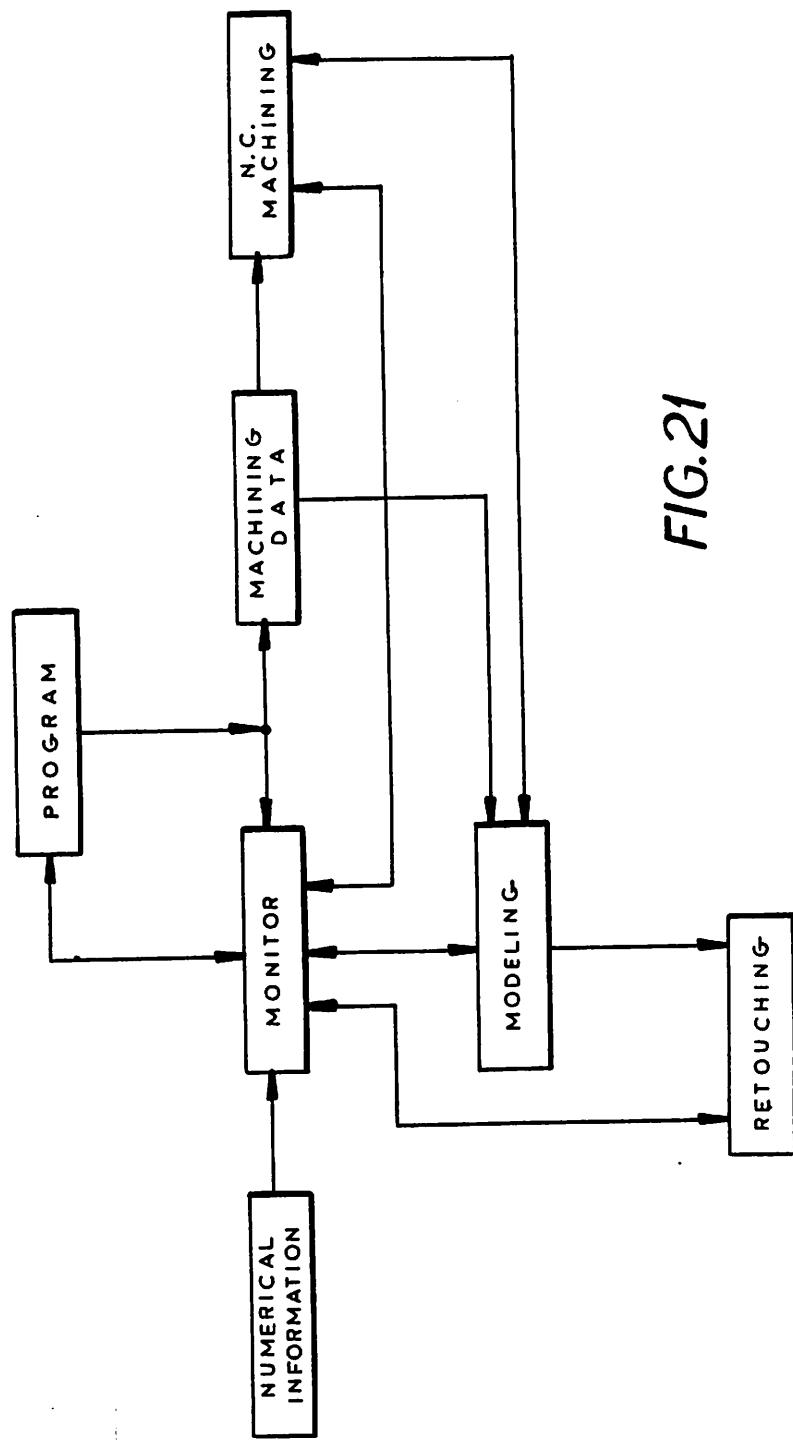


FIG.20





**METHOD OF AND APPARATUS FOR MAKING A PROSTHESIS, ESPECIALLY A DENTAL PROSTHESIS**

**CROSS REFERENCE TO RELATED APPLICATION**

This application is a continuation-in-part of Ser. No. 776 filed Feb. 21, 1984 as a continuation of No. 1,905 filed May 12, 1981, both now abandoned.

**FIELD OF THE INVENTION**

Our present invention relates to a method of and to an apparatus for the making of a prosthesis and especially a dental prosthesis. More particularly, this invention relates to a system for making a dental prosthesis in which, after preparation of the site in the mouth, the dental practitioner need only develop an electronic impression of this site as the sole intervention step before inserting the completed prosthesis.

**BACKGROUND OF THE INVENTION**

The aforementioned application points out that earlier methods of making dental prostheses, e.g. crowns, bridges and replacement teeth, involved a multiplicity of steps, many of which required intervention in the mouth of the patient.

Not only was the patient required to attend the dental practitioner a comparatively large number of times but frequently the intervention was painful, especially during the fitting stages.

In the formation of a dental crown, for example, the operations include the grinding of the tooth to be reduced in order to obtain a truncated stump, the taking of an impression of the stump using an elastomeric path in order to obtain a mold whose hollow part has a shape which is complementary to that of the stump, the casting of plaster into said mold in order to obtain a reproduction of the stump, the preparation of the crown in wax taking into consideration adjacent and antagonistic teeth (a process which was generally highly subjective and the effect of which required high skill and long years of experience by the practitioner), the positioning of the crown in a coating cylinder, the melting out of the wax, the injection of molten metal to replace the wax, stripping and polishing of the metal crown, and, setting of the crown on the stump.

In spite of the fact that these numerous operations were carried out by highly skilled and fastidious dental surgeons, frequent modification of the prosthesis was required after the formation.

Indeed, because of the large number of steps which were involved and the fact that even with mechanical impressions, accurate fits could not be ensured, and because the relationship of each prosthesis to the adjacent and antagonistic teeth was something which had to be gauged subjectively by the practitioner, the production of a dental prosthesis hitherto seldom could be accomplished without the many visits mentioned previously. Indeed, in spite of numerous fitting operations, there was always the danger that the finished prosthesis would cause discomfort to the patient.

Another disadvantage of the earlier systems should also be apparent. For example, the metals used had to be fluid or malleable at easily obtainable temperatures. The numerous steps required the intervention of a laboratory and skilled practitioners at different stages in addition to the dental surgeon. The equipment required

overall, including an oven, sand-blasting machine, inserting equipment, contributed substantially to the cost of producing the prosthesis.

Because the temperature to which the materials were subjected, ranged from room temperature at which some work was done to the casting temperature, to the body temperature of the patient, uncontrolled thermal expansion posed a problem.

In the production of other prostheses, it was necessary to utilize a so-called "bloody impression" when, for example, an impression was required from injured bone. This involved pain and required especially sterile surgical procedures and handling of the impression media. Obviously, repeated fits here were an even more severe drawback.

**OBJECTS OF THE INVENTION**

It is, therefore, a principal object of the present invention to provide an improved method of and apparatus for the production of a prosthesis, and especially a dental prosthesis, whereby the numerous interventions with respect to the body of the patient can be eliminated and indeed many, if not all, of the drawbacks of the earlier systems described can be obviated.

Another object of this invention is to provide a method and apparatus for the fabrication of a dental prosthesis which allows the fabrication of the entire prosthesis or at least a substantial portion thereof by a machining operation outside the mouth of the patient so that the disadvantages of casting techniques are obviated.

Still another object of this invention is to provide a method and apparatus which extends the principles set forth in the above mentioned copending application.

**SUMMARY OF THE INVENTION**

These objects and others which will become apparent hereinafter are attained, in accordance with the invention, in a method whereby an optical impression is taken of the prosthesis site in the mouth and provides an interferogram image of the region at which the prosthesis is to be positioned and its relationship with adjoining teeth and occlusive teeth so that this image can be quantified in terms enabling selection from a stored collection of tooth shapes and sizes in a best-fit approach.

According to the invention, utilizing the data obtained from the best-fit approach, i.e. from the stored data regarding the standard shape and the modifications required to conform the best-fit shape to the tangent place and occlusive conditions from the particular site, a blank is machined by a numerically controlled three-dimensional machine tool so that both the fit to the location and the relationship of the machined prosthesis to the adjoining structures are optimum and determined exclusively by the optical impression.

We have found that, utilizing a computer programmed for computer assisted design of three-dimensional objects to which the optical impression input is fed, and a machine tool of a numerically controlled type which is numerically controlled by this computer, a highly compact apparatus can be provided which allows the dental practitioner to carry out the computer fabrication operation at his office after seeing the patient only once for preparation of the site and the optical impression so that on the next visit the completed prosthesis may be applied. Indeed, since the entire operation

takes only a short period of time, a completed prosthesis may be provided while the patient waits.

While we have used the term "interferogram" to refer to the image received, this expression is used in its broadest sense to refer to the obtention of a three-dimensional or holistic image. The preferred mode of obtaining this image is by interferometry which will be discussed below, although laser holographic techniques may be used as well or in addition.

Consequently, the method of the invention takes an optical impression of that part of the body which is designed to receive the prosthesis, effects a numerical, analog, and, electric clock conversion of the impression into data which is processed taking into account the characteristics of the prosthesis to be obtained and in determining the shape of the latter and sculpturing the prosthesis three-dimensionally with a numerically controlled machine tool.

The process of the invention provides for completely automatic production of a prosthesis with the possibility of preserving with great accuracy the optical impression in all of its holistic aspects. Although the process requires relatively sophisticated and costly apparatus, since it requires a computer and a numerically controlled machine tool, it has the advantage of high precision in the production of the prosthesis and high speed production thereof because it eliminates all of the intermediate phases of earlier techniques.

By eliminating these intermediate phases and the equipment involved in them and because of the gain in time, the cost of the apparatus of the invention is readily amortized, especially since the computer, which is required for the process, can also be used for other purposes.

As noted, an interferogrammatic impression is taken and advantageously two wave sources can be used, namely, an object beam diffracted by the object (the prosthesis site) and a refracted reference beam to obtain the impression in the form of wave interference patterns which can be evaluated and broken down into increments forming the numerical or digital data processed by the computer.

Since the wave interference pattern carries in itself the notion of distance, a holistic image makes it possible to obtain an impression that will not be deformed and will remain intact when carried over via the computer to the machine tool.

In accordance with a first possibility, the interference pattern is generated on a holographic plate while in another possibility the patterns or information are scanned directly utilizing a numerical, analog or electric analog converter.

The impression can advantageously be obtained by projection onto the organ or site to be provided with the prosthesis of a perfectly monochromatic laser wave which does not traumatize the tissue having a power, for example of 100 millijoule. Preferably an interference grating pattern can be projected and this need not use a coherent light source.

The impression can be taken on visible or exposed organs such as two stumps when the prosthesis is a dental crown or even through some media such as the skin or body tissues in order to obtain the impression of subjected organs for osteosynthesis prosthesis without the need for bloody impression techniques.

In a preferred mode of operation, the computer is preprogrammed to contain in memory detailed information regarding the possible prosthesis to be manufac-

tured. This can include information regarding the G. 8 ill of the prosthesis, e.g. standard tooth shapes, in G. 9 illation relating to relationships of the prosthesis G. 10 iacent and antagonistic structures (e.g. information G. 11 illarding an adjoining tooth and antagonistic tooth prost even information regarding the details of attachment G. 12 i the prosthesis to the implantation site (e.g. into w clearances).

The three-dimensional impression of the site is automatically quantified in the manner described stored in the computer which can call up the store regarding the location, standard tooth shapes and the like enabling the best-fit of the tooth or prosthesis to that locus.

The teeth can be displayed on a screen of a monitor or CRT associated with the computer to selection by the dental practitioner. After the selection is made from the stored data regarding the selected tooth sizes may be modified in view of the occupied place and the adjacent structures automatically in accordance with preprogrammed information in the computer and the result is completed with the data of the stump and the site to enable an information set provided to the machine tool for the precise three-dimensional sculpturing of the finished prosthesis from material as assisted by the operator.

FIGS. 1-17

The invention will be further described with reference to the manufacture of a dental crown. This is considered a preferred, but by no means exclusive embodiment.

In accordance with the invention, data roughscribing a plurality of standard teeth is stored in a computer. Data of at least 32 adult teeth, 20 baby teeth, the man possibly some other teeth of special shape must be stored.

Next, an optical image of the implantation site of the prosthesis is obtained. Specifically, the image is obtained by first projecting a luminous grating onto the implantation site.

The grating deformed in accordance with the shape of the site. Interference patterns are then created between the so-deformed grating and a reference grating.

The interference between the two gratings results in the appearance of interference fringes. Interference patterns consisting of the fringes are subjected to log-digital conversion and the resulting values are stored in the computer. The computer then controls the machine tool which manufactures the prosthesis without any further need to inconvenience the patient, further, without any need for manual intervention by the doctor or dentist concerned.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The above and, other objects, features and advantages will become more readily apparent from the following description reference being made to the accompanying drawing in which:

FIGS. 1-4 are interference patterns of four surfaces of one tooth;

FIG. 5 is a block diagram of the system of the present invention;

FIG. 6 is a schematic diagram illustrating the apparatus for creating interference patterns of a tooth;

FIG. 7 is a block diagram of the apparatus linking the interference pattern readout to the machine tool apparatus;

4 include information regarding the relationships of the prosthesis to the implantation site (e.g. information regarding the details of attachment to the implantation site (e.g. ad-

5 dimensional impression of the site is quantified in the manner described by a computer which can call up the stored information, standard tooth shapes and determine the best-fit of the tooth or teeth

be displayed on a screen of a computer associated with the computer to a dental practitioner. After the selected stored data regarding the selection of the tooth to be modified in view of the occlusion, adjacent structures automatically are reprogrammed information in the result is completed with the data which has been derived from the standard model stored in the computer; a machine tool for the precise machining of the finished prosthesis is controlled by the operator.

6 FIG. 17 shows four views of the final prosthesis in 25

with the invention, data roughly of standard teeth is stored in a computer at least 32 adult teeth, 20 baby teeth and other teeth of special shape must

7 image of the implantation site is obtained. Specifically, the image is projected onto a luminous grating onto

8 formed in accordance with the interference patterns are then created between the two gratings resulting in interference fringes. Interference fringes are subjected to a computer. The computer then controls the manufacture of the prosthesis without inconvenience the patient and need for manual intervention concerned.

9 SECTION OF THE DRAWING  
other objects, features and advantages more readily apparent from the reference being made to the accompanying drawings:

10 reference patterns of four surfaces

diagram of the system of the present

11 diagram illustrating the appearance patterns of a tooth; diagram of the apparatus linking the readout to the machine tool appara-

12 FIG. 8 illustrates the combination of a plurality of gratings to create a three-dimensional model by CAD (computer assisted design);

13 FIG. 9 illustrates four views of the implantation zone of the prosthesis;

14 FIG. 10 illustrates the actual planes limiting the volume into which the prosthesis must be inserted;

15 FIG. 11 illustrates the fitting of a standard tooth derived from computer memory into the volumetric space of the prosthesis;

16 FIG. 12 illustrates movement of the center of gravity of the standard tooth onto the center of gravity of the implantation zone;

17 FIG. 13 illustrates deformation of the external surfaces of the standard tooth to fit into the volume of the

18 prosthesis;

19 FIG. 14 illustrates the cement film on which the prosthesis is to be held;

20 FIG. 15 illustrates the superposition of the bottom one of the modified standard tooth with the corresponding plane of the implantation site;

21 FIG. 16 illustrates the actual model of the prosthesis result is completed with the data which has been derived from the standard model stored in the computers;

22 FIG. 17 shows four views of the final prosthesis in 25

23 FIGS. 18, 19 and 20 illustrate the machining of successive planes under program control; and

24 FIG. 21 is a function diagram for the apparatus of FIG. 7.

## SPECIFIC DESCRIPTION

The present invention will be discussed with regard to the manufacture of a crown for a tooth. It should be noted that the invention can be equally used for other types of prosthetic devices such as osteosynthetic. It must further be noted that understanding of the invention, though not operation of the resulting equipment, requires a person skilled in the art of Computer Aided Design and Manufacture (CAD/CAM). Specifically, a skill in the utilization of commercially available CAD/CAM equipment is essential.

Setting up the computer so that the method of the present invention may be used, in the case of a dental prosthesis involves the insertion into memory of data roughly defining 32 adult teeth, 20 baby teeth and, as required, additional teeth having odd shapes.

The data defining the shape of each of the above-mentioned teeth is entered into the memory of the computer in numerical form. Each tooth is defined by x, y, z coordinates of a plurality of points, as well as by a number of reference values, such as the center of gravity, and lines, circles or surfaces which may be mathematically defined. A computer aided design system (CAD) suitable for this purpose is, for example, the "EUCLID AND VAX" (Geometric Construction), CAD, of the Digital Equipment Corp.

It should be noted that this entry into memory of rough or standard tooth shapes is a one time operation and need not be repeated for each patient.

After the dentist has prepared the site of implantation of the prosthesis in the conventional manner, he proceeds to project a luminous grating onto the implantation site with either coherent or non-coherent light. The grating deforms in dependence on the shape of the site, so that interference fringes are created between the so-deformed grating and a reference grating which is not deformed.

FIGS. 1-4 are examples of so-created patterns. The interference patterns illustrated in FIGS. 1-4 correspond to four optical recordings of four faces of a tooth.

Reading out of the images may take place after recording on a holographic plate or other suitable recording medium or, preferably, directly by a television camera or a plasma display.

This is illustrated generally by steps 20 and 30 in FIG. 5.

FIG. 6 illustrates a light source, 101, projecting a grating onto the tooth site. The grating is correspondingly deformed and an interference pattern, 102, created by superimposition of an undeformed reference grating.

The pattern is scanned by a TV camera 103. Plane 104 represents an interference plane. The pickup can be in a video camera or a CCD (chargecoupled device) camera.

The equipment linking the camera sensor to the final machine tool, for example a milling machine, is illustrated in FIG. 7. A television camera 103 scans the interference pattern. An analog/digital converter 104 converts the scanned data and stores it in memory. The image is also projected onto a cathode ray screen 106. The image on the screen is subjected to processing for purposes of simplification, as will be explained in greater detail below. For this purpose, the operator controls a control console 108 which, in turn, controls an image processor 107. After the image has been processed, it is subjected to computer-aided design in a computer 109, also to be described in greater detail below. The output of computer 109 is displayed on a suitable screen 110, the image on which may be modified by operation of a modification unit 111. The final output of the computer is numerical control data which, through a numerical control unit 112 controls the final machine tool, here a micro-milling machine 113 (see also FIG. 21). Processing of the interference patterns proceeds as follows:

The interference patterns have certain contour lines which are a function of the volume of the tooth.

For any point, the xy coordinates are obtained by direct read-out. The third coordinate, z, can easily be calculated with the aid of a formula giving the distance h between two interference fringes;

$$h = 2aD^2/bF$$

As illustrated in FIG. 5:

F is the focal distances;

b is the distance between the transmitting and receiving objectives;

a is the spacing between grating lines;

and D is the distance between the apparatus and the interference plane.

The third coordinate z is given by the formula

$$a = (2aD^2/bF)n$$

where n represents the number of fringes.

Before the proceeding to determine the different coordinates of each point, the image is reduced to a skeletal version so that the number of reference values of z is the least possible. This is accomplished by reducing the number of points in each curve and reducing the number of curves, keeping in mind the minimum degree of accuracy which must be preserved.

Preferably, the coordinates of each point are obtained using FORTRAN, for example FORTRAN 22, by which, for each value of z, the corresponding values of x and y are found.

The analog/digital conversion of the data takes place very simply by counting of fringes or by sinusoidal interpolation between fringes. It is considered that a fringe is black and that the space between fringes is white. After the simplification, each fringe corresponds to a black line of several microns. The value 0 is assigned to each black point, while the value 1 is applied to each white point. The formula mentioned above then can be used to determine the value of z correctly. The values of x and y are given by the position of the point being analyzed on the image plane.

All these operations are carried out by the computer which, for this purpose, is equipped especially with commercially available programs such as VAX730 of the Digital Equipment Corporation or with booting or operating cards such as Thompson CSF (31138 ANB-TIBLOWING) and associated Program (THX 5002: Frequency Generator and Command Logic, and THX 5003: Video channel and analog digital conversion).

To the extent that the implantation site and the adjacent areas of the prosthesis necessitate views from different angles, the computer will reconstitute the overall shape of the site by combining such views as is illustrated in FIG. 8. This figure was obtained by the Euclid and Vax, FUSION design package.

Next, the determination of the volume (envelope) of the prosthesis must be carried out.

This is a two-step operation.

(a) imaging of the implantation zone of the prosthesis; (FIG. 9 shows this zone from four angles);

(b) adaptation of the standard form or rough outline of the tooth stored in the computer memory to the visualized shape of the prosthesis.

First, the operator causes an area to appear on a cathode ray screen into which the standard form of a theoretical tooth in the memory is inserted. This volume is parallelepiped and is obtained by geometric determination of 6 planes, taking into consideration the contact zones with the neighboring teeth (planes 1 and 2), the front and rear faces of the neighboring teeth (planes 3 and 4) the contacting surface of the opposite teeth (plane 5) and finally the lower limit of the implantation zone of the prosthesis (plane 6). This defines the real limits of the volume into which the prosthesis must be inserted (FIG. 10).

To avoid having to enter excessive data into the computer, the prosthesis is generated by adaptation of a standard tooth shape in the computer memory to fit into this volume.

As mentioned above, the operator first causes the theoretical tooth stored in the memory which is closest to the tooth to be fitted to appear on the screen (FIG. 11). By using a CAD/CAM package (Euclid: Geometric Transformation), and by controlling the cathode ray tube, the operator matches the form of the theoretical tooth to the previously determined volume or envelope. This adaptation is first made by moving the center of gravity of the standard tooth onto the center of gravity of the implantation site of the prosthesis (FIG. 12), then by deformation of the surfaces of the outline of the standard tooth, so that they are tangent to the planes limiting the volume of the previously determined envelope (FIG. 13).

The exterior surface of the prosthesis has thus been defined. The interior (lower) surface corresponds to that of the implantation site. The logic package (Euclid) then determines the actual volume of the prosthesis, taking into consideration the exterior surface previously

defined, the shape of the implantation site, and finally, other factors such as the thickness of the cement film which will hold the prosthesis (FIG. 14). The combination of interior and exterior surfaces is effected by superposition of the implantation site on the lower limit of the standard tooth, as modified (FIG. 15).

The computer aided design system, such as Euclid and VAX, allows the transformation of the theoretical model into the actual model (FIG. 16). The results can be visualized according to predetermined views (FIG. 17). At this stage, visualization of the actual model of the prosthesis and its adjoining areas make it possible to verify the exact shape of the model and, if necessary, make modifications at particular points.

After the real model has thusly been determined, the CAD/CAM system controls the manufacture of the prosthesis or, depending upon the material utilized, of a casting into which the material for the prosthesis will be poured. FIG. 18 illustrates the program for manufacturing control of successive planes, as generated by Euclid. (FIGS. 19 and 20).

The process of the present invention thus has several principal stages which may be summarized as follows:

- (a) one time creation of an optical pattern independently of the object itself and connected only to an interference phenomenon, either optical-optical or optical-electronic;
- (b) immediate carrying out of an analog-digital conversion;
- (c) determining the external and internal shape of the prosthesis solely by mathematical means within the computer, on the basis of CAD/CAM techniques, the computer having stored data defining standard shapes, such as the shape of the adult and baby teeth, which may be modified in accordance with the interference patterns derived from the particular patient.

It must be noted that nowhere in the process of the present invention is wax or resin used to make an imprint nor is there any manual adjustment of the prosthesis.

The process has been carried out successfully by the inventors to manufacture a prototype which functions perfectly and which allowed a dental prosthesis to be manufactured within 20 minutes.

It must of course be understood that, in particular, the process of the present invention makes use of a truly interferometric method. In a preferred embodiment, the interference patterns are not obtained by interference of a reference beam and a diffraction beam, but by interference between a grating which is not deformed and a luminous grating which is deformed by the zone being analyzed. It should be noted that it is not measurements of an object, but solely interference phenomena derived from the object which are utilized in the automatic manufacture of the prosthesis.

This interferometric method allows analog-digital conversion with the restricted financial means available in a, for example, dental office. The shape of the prosthesis is then derived strictly mathematically by a CAD/CAM system.

Further, the interferometric method allows the optical interference patterns to be obtained in a very short time, namely several microseconds (scanning at 5 MHz), data processing taking place in several seconds, as opposed to other methods which require either a long readout time for a short data processing time or a short readout time but a long processing time (30 minutes to an hour) with very powerful computers which are not

financially within office.

We claim:

1. A method of comprises, carrying the steps of: creating an inter corresponding in the buccal scanning said in site data; processing said data; machining said p cal cavity dir tool data, said plurality of st and wherein said s comprises g volume of data, displa lecting from terns the pa said organ, tern, and fit lobe under desired sha puter comp said selected create said

2. A method as of processing said modification of sa upon the material

3. Apparatus for determined organ

means for creati site data cor view of said c means for scann verting said s computer means verting mean said digital s under operat sis shape and shape into ma

financially within the reach of, for example, a dental office.

We claim:

1. A method of producing a dental prosthesis which comprises, carrying out under the control of a computer the steps of:

creating an interference pattern containing site data corresponding to a three-dimensional view of a site in the buccal cavity;

scanning said interference pattern to produce digital site data;

processing said digital site data to create machine tool data;

machining said prosthesis to fit said site and said buccal cavity directly under control of said machine tool data, said computer having a memory having a plurality of standard tooth patterns stored therein; and

wherein said step of processing said digital site data comprises generating an envelope enclosing the volume of said prosthesis from said digital site data, displaying the so-produced envelope, selecting from said plurality of standard tooth patterns the pattern corresponding most closely to said organ, displaying the so-selected tooth pattern, and fitting said tooth pattern into said envelope under operator control, thereby creating a desired shape display, and wherein said computer computes said machine tool data based on said selected standard tooth shape as modified to create said desired shape display.

2. A method as set forth in claim 1, wherein said step of processing said digital site data further comprises modification of said machine tool data in dependence upon the material of said prosthesis.

3. Apparatus for creating a prosthesis of an organ at a determined organ site, comprising:

means for creating an interference pattern containing site data corresponding to a three-dimensional view of said organ site;

means for scanning said interference pattern and converting said so-scanned pattern to digital site data;

computer means connected to said scanning and converting means for creating an optical image from said digital site data, and modifying said image under operator control to create a desired prosthesis shape and converting said desired prosthesis shape into machine tool data; and

machining means connected to said computer means for manufacturing said prosthesis under control of said machine tool data.

4. Apparatus as set forth in claim 3, wherein said prosthesis is a ground for a tooth; wherein said computer further comprises a memory having a plurality of standard tooth patterns stored therein;

wherein said optical image is an envelope enclosing the volume of said prosthesis; and

wherein said modifying means comprises a selecting means for selecting one of said plurality of standard tooth patterns and adjusting said tooth pattern under operator control into said envelope, the so-modified standard tooth pattern constituting said desired prosthesis shape.

5. A method of making a dental prosthesis which comprises the steps of:

storing in a computer memory, data representing standard tooth shapes and sizes, relationships between teeth and adjacent and occlusive teeth and characteristics for securing a prosthesis to a prepared site, and machining instructions for shaping a blank to the configuration of a dental prosthesis for direct implantation;

preparing a site in the mouth of a patient to receive a dental prosthesis;

projecting optically a grating upon said site in the mouth of said patient and generating an interference pattern representing a holistic impression of said site and its relationship to adjacent structures;

converting said interference pattern into data along x, y, z coordinates in a cartesian coordinate system representing machining of a blank to fit said site;

matching data obtained by said impression with said computer to standard prosthesis shapes and sizes and selecting a best-fit shape and size and modifying same in said computer to match said site;

numerically controlling said machine tool with said x,y,z coordinate data and x,y,z coordinate data from the match made by the computer and representing the shape and size of said prosthesis to totally and three-dimensionally fabricate said prosthesis in said machine tool; and

implanting the totally fabricated prosthesis at said site.

6. The method defined in claim 5 wherein said prosthesis is a dental crown.

7. The method defined in claim 6 wherein said pattern is skeletonized to reduce the number of points which are matched by the data stored in said computer.

# United States Patent [19]

Duret et al.

[11] Patent Number: 4,742,464

[45] Date of Patent: \* May 3, 1988

[54] **METHOD OF MAKING A PROSTHESIS,  
ESPECIALLY A DENTAL PROSTHESIS**

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Grenoble (Isere), both of France

[\*] Notice: The portion of the term of this patent  
subsequent to Sep. 9, 2003 has been  
disclaimed.

[21] Appl. No.: 903,595

[22] Filed: Sep. 3, 1986

**Related U.S. Application Data**

[60] Division of Ser. No. 673,655, Nov. 21, 1984, Pat. No.  
4,663,720, which is a continuation-in-part of Ser. No.  
580,776, Feb. 21, 1984, abandoned, which is a continuation  
of Ser. No. 262,905, May 12, 1981, abandoned,  
which is a continuation-in-part of Ser. No. 485,059,  
Apr. 14, 1983, Pat. No. 4,611,288.

[51] Int. Cl. 4 ..... G06F 15/00; A61C 9/00

[52] U.S. Cl. ..... 364/474; 433/214

[58] Field of Search ..... 364/474, 475, 168;  
356/347, 357, 358; 433/204, 213, 214, 223, 55,  
68, 73

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Primary Examiner—Jerry Smith

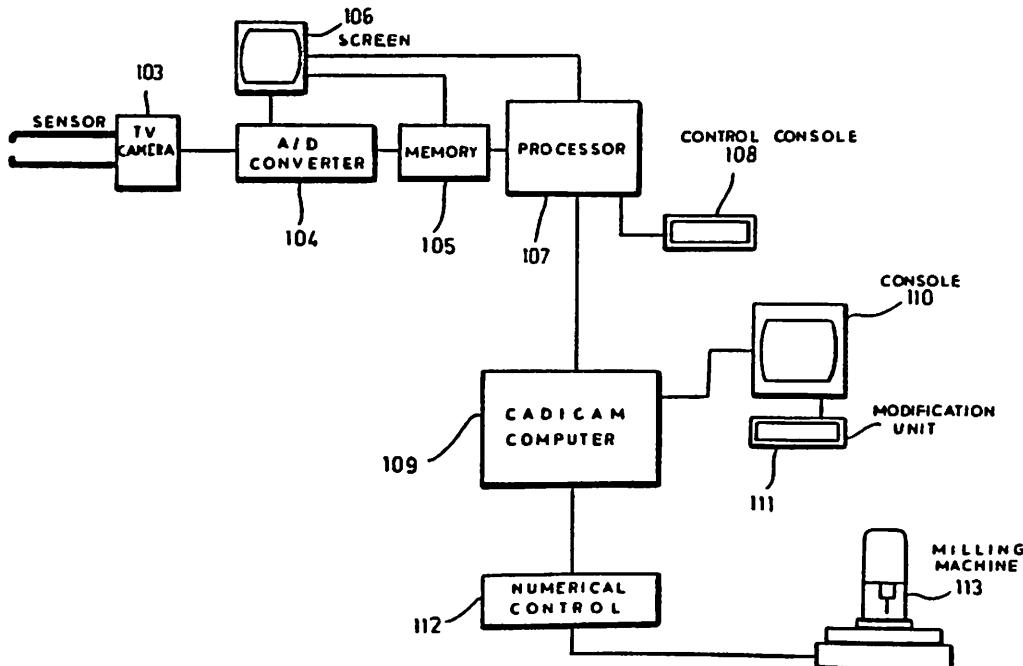
Assistant Examiner—Allen MacDonald

Attorney, Agent, or Firm—Karl F. Ross; Herbert Dubno

[57] **ABSTRACT**

A method of making a dental prosthesis in which data representing standard tooth shapes and sizes, relationships between teeth and adjacent and occlusive teeth and characteristics for securing a prosthesis to a prepared site, and machining instructions for shaping a blank to the configuration of a dental prosthesis for direct implantation are stored in a computer memory. After preparing a site in the mouth of a patient to receive a dental prosthesis, the dental surgeon projects optically a grating upon said site in the mouth of the patient and generates an interference pattern representing a holistic impression of said site and its relationship to adjacent structures. The interference pattern is converted into data along x,y,z coordinates in a cartesian coordinate system representing machining of a blank to fit said site and matching data obtained by comparing the impression with the computer standards are used to select a best-fit shape and size. A machine tool is numerically controlled with the x,y,z coordinate data and x,y,z coordinate data from the match made by the computer and representing the shape and size of the prosthesis to totally and three-dimensionally fabricate said prosthesis in said machine tool.

5 Claims, 8 Drawing Sheets



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U.S. Patent

May 3, 1988

Sheet 1 of 9

4,742,464

FIG.1

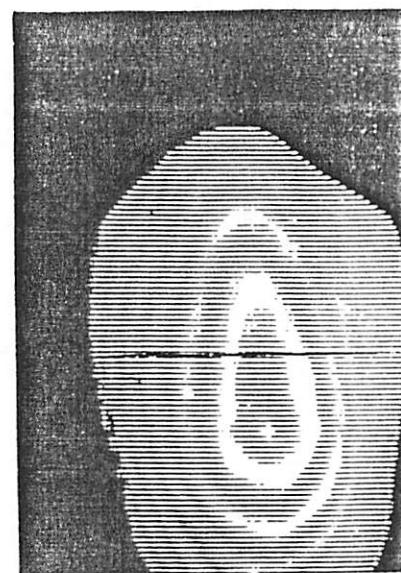
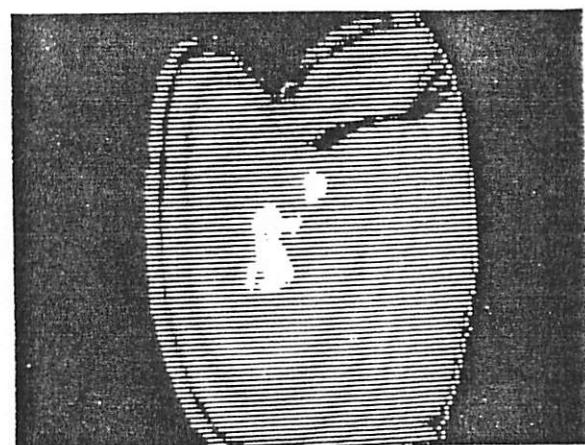


FIG.2



U.S. Patent

May 3, 1988

Sheet 2 of 9

4,742,464

FIG.3

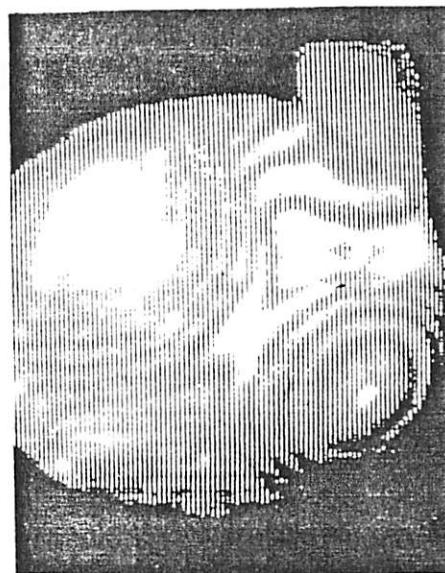


FIG.4



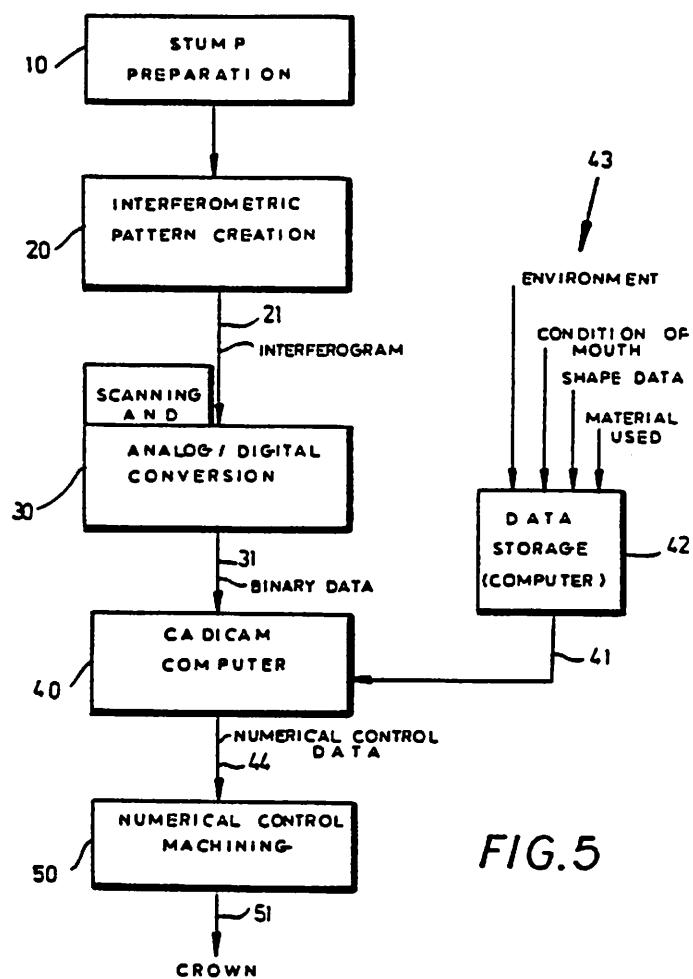
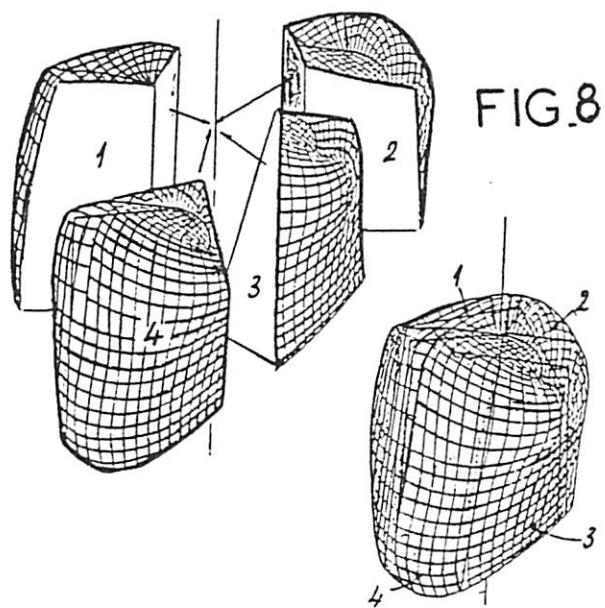
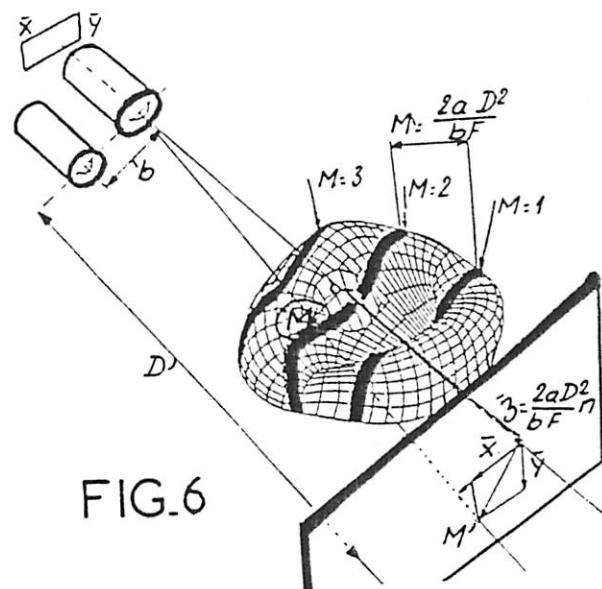


FIG.5



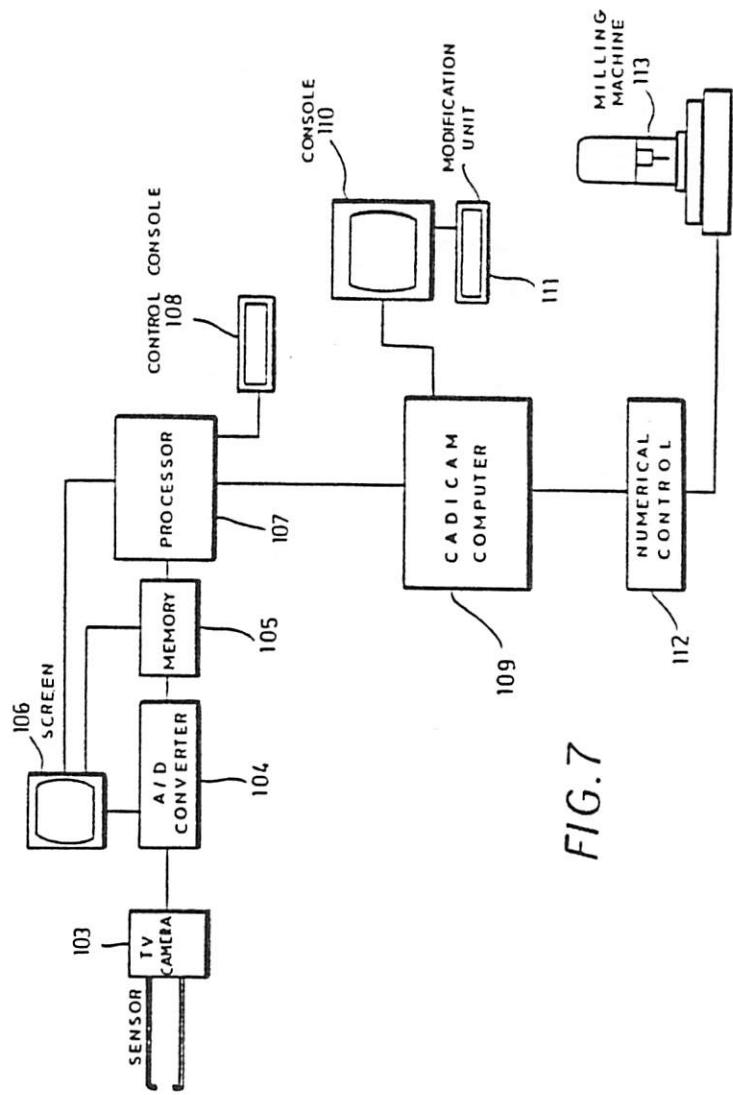


FIG. 7

FIG.9

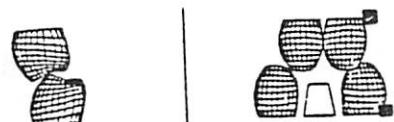


FIG.10

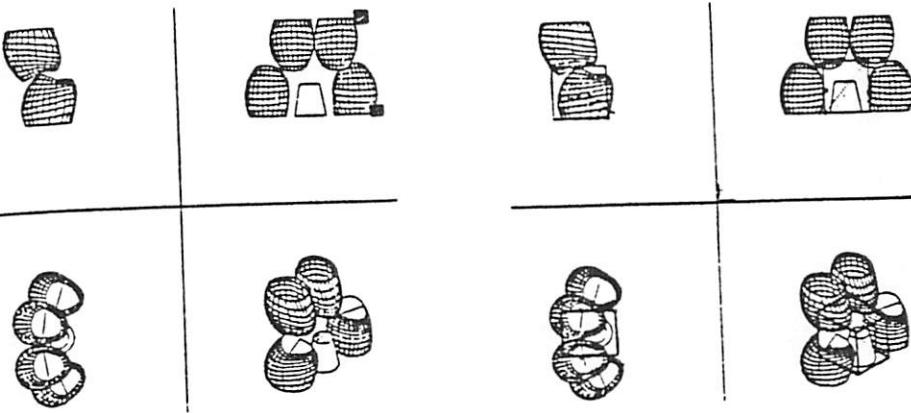


FIG.11

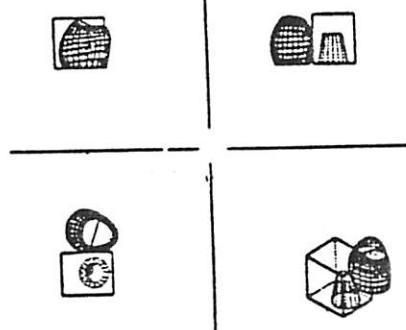


FIG.12

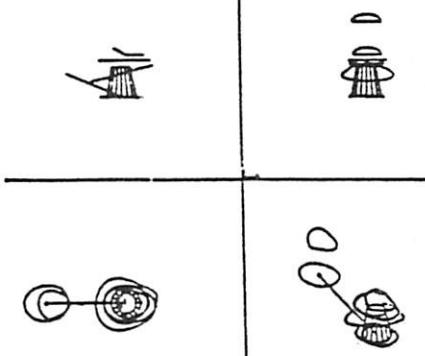
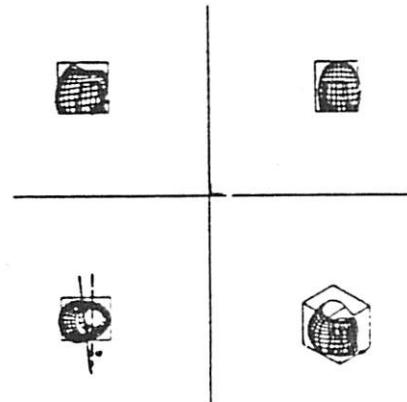


FIG.13



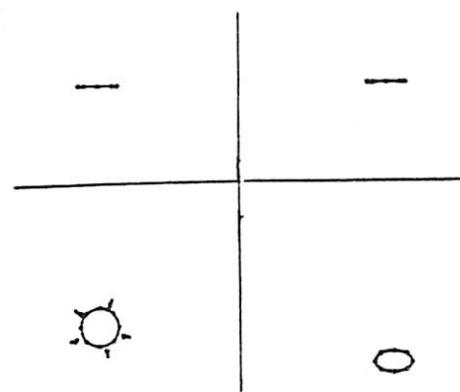


FIG 14

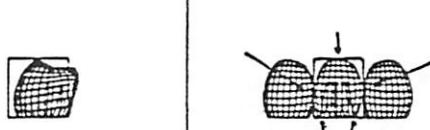


FIG 15

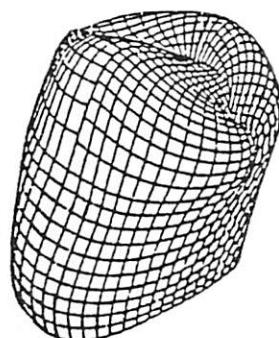
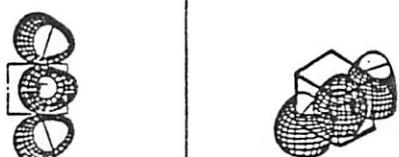


FIG 16

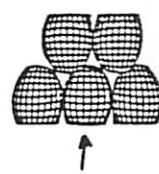
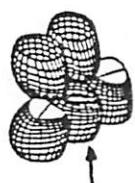
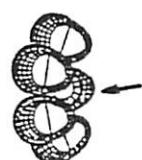


FIG 17



POINT NUMÉRO 1	X = 1.43 286	Y = 0.09 771	Z = -0.32 480
POINT NUMÉRO 2	X = 1.47 239	Y = -0.03 848	Z = -0.32 482
POINT NUMÉRO 3	X = 1.84 684	Y = -0.14 006	Z = -0.32 481
POINT NUMÉRO 4	X = 1.84 498	Y = -0.20 727	Z = -0.32 480
POINT NUMÉRO 5	X = 1.76 782	Y = -0.23 678	Z = -0.32 480
POINT NUMÉRO 6	X = 1.87 423	Y = -0.23 033	Z = -0.32 480
POINT NUMÉRO 7	X = 1.98 552	Y = -0.19 006	Z = -0.32 480
POINT NUMÉRO 8	X = 2.08 213	Y = -0.11 948	Z = -0.32 480
POINT NUMÉRO 9	X = 2.15 522	Y = -0.02 340	Z = -0.32 480
POINT NUMÉRO 10	X = 2.19 637	Y = 0.09 211	Z = -0.32 481
POINT NUMÉRO 11	X = 2.19 768	Y = 0.21 962	Z = -0.32 481
POINT NUMÉRO 12	X = 2.15 205	Y = 0.35 027	Z = -0.32 482
POINT NUMÉRO 13	X = 2.04 011	Y = 0.50 696	Z = -0.32 480
POINT NUMÉRO 14	X = 1.92 823	Y = 0.61 981	Z = -0.32 480
POINT NUMÉRO 15	X = 1.82 272	Y = 0.68 935	Z = -0.32 482
POINT NUMÉRO 16	X = 1.72 603	Y = 0.72 258	Z = -0.32 481
POINT NUMÉRO 17	X = 1.63 922	Y = 0.72 591	Z = -0.32 480
POINT NUMÉRO 18	X = 1.56 338	Y = 0.70 243	Z = -0.32 480
POINT NUMÉRO 19	X = 1.50 010	Y = 0.65 231	Z = -0.32 480
POINT NUMÉRO 20	X = 1.45 189	Y = 0.57 233	Z = -0.32 480
POINT NUMÉRO 21	X = 1.42 147	Y = 0.45 562	Z = -0.32 482
POINT NUMÉRO 22	X = 1.41 385	Y = 0.29549	Z = -0.32 480

FIG.18



FIG.19

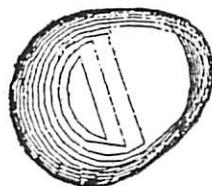
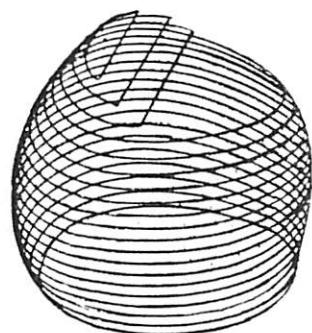


FIG.20



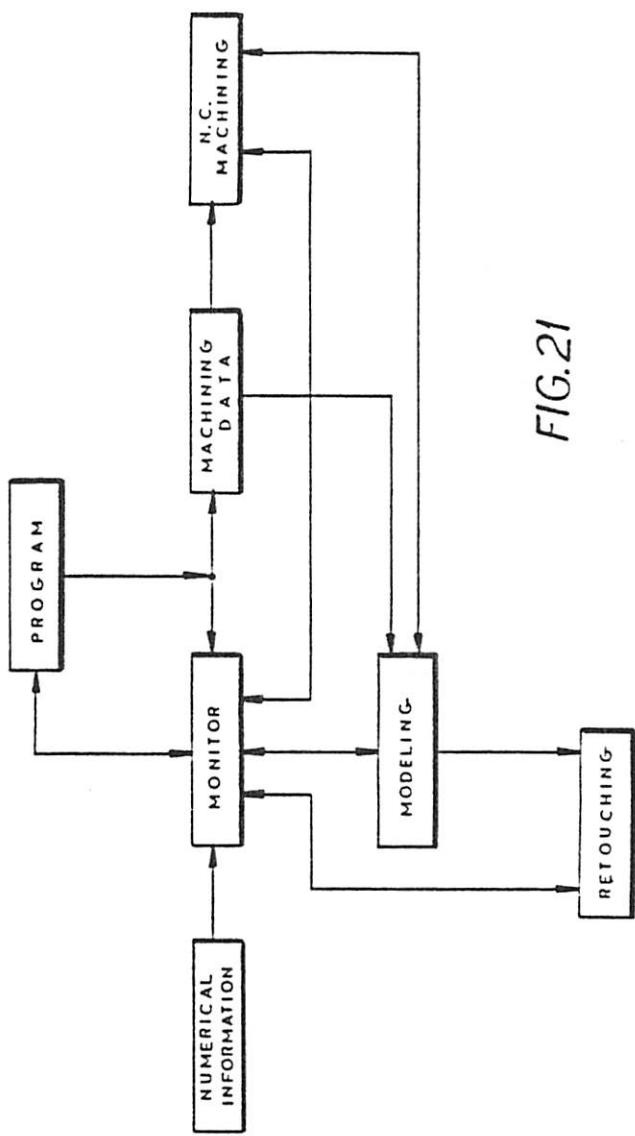


FIG.21

## METHOD OF MAKING A PROSTHESIS, ESPECIALLY A DENTAL PROSTHESIS

### CROSS REFERENCE TO RELATED APPLICATIONS

This application is a division of Ser. No. 06/673,655 filed Nov. 1984 (now U.S. Pat. No. 4,663,720) as a continuation-in-part of Ser. No. 06/580,776 filed Feb. 21, 1984 (now abandoned) which is a continuation of Ser. No. 06/262,905 filed May 12, 1981 (now abandoned) and is also a continuation-in-part of copending application Ser. No. 06/685,509 filed Apr. 14, 1983 (now U.S. Pat. No. 4,611,288).

### FIELD OF THE INVENTION

Our present invention relates to a method of and to an apparatus for the making of a prosthesis and especially a dental prosthesis. More particularly, this invention relates to a system for making a dental prosthesis in which, after preparation of the site in the mouth, the dental practitioner need only develop an electronic impression of this site as the sole intervention step before inserting the completed prosthesis.

### BACKGROUND OF THE INVENTION

The aforementioned application points out that earlier methods of making dental prostheses, e.g. crowns, plates and replacement teeth, involved a multiplicity of steps, many of which required intervention in the mouth of the patient.

Not only was the patient required to attend the dental practitioner a comparatively large number of times but frequently the intervention was painful, especially during the fitting stages.

In the formation of a dental crown, for example, the operations include the grinding of the tooth to be replaced in order to obtain a truncated stump, the taking of an impression of the stump using an elastomeric path in order to obtain a mold whose hollow part has a shape which is complementary to that of the stump, the casting of plaster into said mold in order to obtain a reproduction of the stump, the preparation of the crown in wax taking into consideration adjacent and antagonistic teeth (a process which was generally highly subjective and the effect of which required high skill and long years of experience by the practitioner), the positioning of the crown in a coating cylinder, the melting out of the wax, the injection of molten metal to replace the wax, stripping and polishing of the metal crown, and, setting of the crown on the stump.

In spite of the fact that these numerous operations were carried out by highly skilled and fastidious dental surgeons, frequent modification of the prosthesis was required after the formation.

Indeed, because of the large number of steps which were involved and the fact that even with mechanical impressions, accurate fits could not be ensured, and because the relationship of each prosthesis to the adjacent and antagonistic teeth was something which had to be gauged subjectively by the practitioner, the production of a dental prosthesis hitherto seldom could be accomplished without the many visits mentioned previously. Indeed, in spite of numerous fitting operations, there was always the danger that the finished prosthesis would cause discomfort to the patient.

Another disadvantage of the earlier systems should also be apparent. For example, the metals used had to be

fluid or malleable at easily obtainable temperatures. The numerous steps required the intervention of a laboratory and skilled practitioners at different stages in addition to the dental surgeon. The equipment required overall, including an oven, sand-blasting machine, inserting equipment, contributed substantially to the cost of producing the prosthesis.

Because the temperature to which the materials were subjected, ranged from room temperature at which some work was done to the casting temperature, to the body temperature of the patient, uncontrolled thermal expansion posed a problem.

In the production of other prostheses, it was necessary to utilize a so-called "bloody impression" when, for example, an impression was required from injured bone. This involved pain and required especially sterile surgical procedures and handling of the impression media. Obviously, repeated fits here were an even more severe drawback.

### OBJECTS OF THE INVENTION

It is, therefore, a principal object of the present invention to provide an improved method of and apparatus for the production of a prosthesis, and especially a dental prosthesis, whereby the numerous interventions with respect to the body of the patient can be eliminated and indeed many, if not all, of the drawbacks of the earlier systems described can be obviated.

Another object of this invention is to provide a method and apparatus for the fabrication of a dental prosthesis which allows the fabrication of the entire prosthesis or at least a substantial portion thereof by a machining operation outside the mouth of the patient so that the disadvantages of casting techniques are obviated.

Still another object of this invention is to provide a method and apparatus which extends the principles set forth in the above mentioned copending application.

### SUMMARY OF THE INVENTION

These objects and others which will become apparent hereinafter are attained, in accordance with the invention, in a method whereby an optical impression is taken of the prosthesis site in the mouth and provides an interferogram image of the region at which the prosthesis is to be positioned and its relationship with adjoining teeth and occlusive teeth so that this image can be quantified in terms enabling selection from a stored collection of tooth shapes and sizes in a best-fit approach.

According to the invention, utilizing the data obtained from the best-fit approach, i.e. from the stored data regarding the standard shape and the modifications required to conform the best-fit shape to the tangent place and occlusive conditions from the particular site, a blank is machined by a numerically controlled three-dimensional machine tool so that both the fit to the location and the relationship of the machined prosthesis to the adjoining structures are optimum and determined exclusively by the optical impression.

We have found that, utilizing a computer programmed for computer assisted design of three-dimensional objects to which the optical impression input is fed, and a machine tool of a numerically controlled type which is numerically controlled by this computer, a highly compact apparatus can be provided which allows the dental practitioner to carry out the computer fabrication operation at his office after seeing the pa-



FIG. 7 is a block diagram of the apparatus linking the interference pattern readout to the machine tool apparatus;

FIG. 8 illustrates the combination of a plurality of views to create a three-dimensional model by CAD (computer assisted design);

FIG. 9 illustrates four views of the implantation zone of the prosthesis;

FIG. 10 illustrates the actual planes limiting the volume into which the prosthesis must be inserted;

FIG. 11 illustrates the fitting of a standard tooth derived from computer memory into the volumetric space of the prosthesis;

FIG. 12 illustrates movement of the center of gravity of the standard tooth onto the center of gravity of the implantation zone;

FIG. 13 illustrates deformation of the external surfaces of the standard tooth to fit into the volume of the prosthesis;

FIG. 14 illustrates the cement film on which the prosthesis is to be held;

FIG. 15 illustrates the superposition of the bottom plane of the modified standard tooth with the corresponding plane of the implantation site;

FIG. 16 illustrates the actual model of the prosthesis which has been derived from the standard model stored in the computers;

FIG. 17 shows four views of the final prosthesis in place;

FIGS. 18, 19 and 20 illustrate the machining of successive planes under program control; and

FIG. 21 is a function diagram for the apparatus of FIG. 7.

#### SPECIFIC DESCRIPTION

The present invention will be discussed with regard to the manufacture of a crown for a tooth. It should be noted that the invention can be equally used for other types of prosthetic devices such as osteosynthetic. It must further be noted that understanding of the invention, though not operation of the resulting equipment, requires a person skilled in the art of Computer Aided Design and Manufacture (CAD/CAM). Specifically, skill in the utilization of commercially available CAD/CAM equipment is essential.

Setting up the computer so that the method of the present invention may be used, in the case of a dental prosthesis involves the insertion into memory of data roughly defining 32 adult teeth, 20 baby teeth and, as required, additional teeth having odd shapes.

The data defining the shape of each of the above-mentioned teeth is entered into the memory of the computer in numerical form. Each tooth is defined by x, y, z coordinates of a plurality of points, as well as by a number of reference values, such as the center of gravity, and lines, circles or surfaces which may be mathematically defined. A computer aided design system (CAD) suitable for this purpose is, for example, the "EUCLID AND VAX" (Geometric Construction), CAD, of the Digital Equipment Corp.

It should be noted that this entry into memory of rough or standard tooth shapes is a one time operation and need not be repeated for each patient.

After the dentist has prepared the site of implantation of the prosthesis in the conventional manner, he proceeds to project a luminous grating onto the implantation site with either coherent or non-coherent light. The grating deforms in dependence on the shape of the site,

so that interference fringes are created between the so-deformed grating and a reference grating which is not deformed.

FIGS. 1-4 are examples of so-created patterns. The interference patterns illustrated in FIGS. 1-4 correspond to four optical recordings of four faces of a tooth.

Reading out of the images may take place after recording on a holographic plate or other suitable recording medium or, preferably, directly by a television camera or a plasma display.

This is illustrated generally by steps 20 and 30 in FIG. 5. FIG. 6 illustrates a light source, 101, projecting a grating onto the tooth site. The grating is correspondingly deformed and an interference pattern, 102, created by superimposition of an undeformed reference grating.

The pattern is scanned by a TV camera 103. Plane 104 represents an interference plane. The pickup can be in a video camera or a CCD (chargecoupled device) camera.

The equipment linking the camera sensor to the final machine tool, for example a milling machine, is illustrated in FIG. 7. A television camera 103 scans the interference pattern. An analog/digital converter 104 converts the scanned data and stores it in memory. The image is also projected onto a cathode ray screen 106. The image on the screen is subjected to processing for purposes of simplification, as will be explained in greater detail below. For this purpose, the operator controls a control console 108 which, in turn, controls an image processor 107. After the image has been processed, it is subjected to computer-aided design in a computer 109, also to be described in greater detail below. The output of computer 109 is displayed on a suitable screen 110, the image on which may be modified by operation of a modification unit 111. The final output of the computer is numerical control data which, through a numerical control unit 112 controls the final machine tool, here a micro-milling machine 113 (see also FIG. 21). Processing of the interference patterns proceeds as follows:

The interference patterns have certain contour lines which are a function of the volume of the tooth.

For any point, the xy coordinates are obtained by direct read-out. The third coordinate, z, can easily be calculated with the aid of a formula giving the distance h between two interference fringes;

$$h = 2aD^2/bF$$

As illustrated in FIG. 5:

F is the focal distance;

b is the distance between the transmitting and receiving objectives;

a is the spacing between grating lines;

and D is the distance between the apparatus and the interference plane.

The third coordinate z is given by the formula

$$a = (2aD^2/bF)n$$

where n represents the number of fringes.

Before the proceeding to determine the different coordinates of each point, the image is reduced to a skeletal version so that the number of reference values of z is the least possible. This is accomplished by reducing the number of points in each curve and reducing the number of curves, keeping in mind the minimum degree of accuracy which must be preserved.

Preferably, the coordinates of each point are obtained using FORTRAN, for example FORTRAN 22, by which, for each value of z, the corresponding values of x and y are found.

The analog/digital conversion of the data takes place very simply by counting of fringes or by sinusoidal interpolation between fringes. It is considered that a fringe is black and that the space between fringes is white. After the simplification, each fringe corresponds to a black line of several microns. The value 0 is assigned to each black point, while the value 1 is applied to each white point. The formula mentioned above then can be used to determine the value of z correctly. The values of x and y are given by the position of the point being analyzed on the image plane.

All these operations are carried out by the computer which, for this purpose, is equipped especially with commercially available programs such as VAX730 of the Digital Equipment Corporation or with booting or operating cards such as Thompson CSF (31138 ANTI-BLOWING) and associated Program (THX 5002: Frequency Generator and Command Logic, and THX 5003: Video channel and analog digital conversion).

To the extent that the implantation site and the adjacent areas of the prosthesis necessitate views from different angles, the computer will reconstitute the overall shape of the site by combining such views as is illustrated in FIG. 8. This figure was obtained by the Euclid and Vax, FUSION design package.

Next, the determination of the volume (envelope) of the prosthesis must be carried out.

This is a two-step operation.

(a) imaging of the implantation zone of the prosthesis; (FIG. 9 shows this zone from four angles);

(b) adaptation of the standard form or rough outline of the tooth stored in the computer memory to the visualized shape of the prosthesis.

First, the operator causes an area to appear on a cathode ray screen into which the standard form of a theoretical tooth in the memory is inserted. This volume is parallelepiped and is obtained by geometric determination of 6 planes, taking into consideration the contact zones with the neighboring teeth (planes 1 and 2), the front and rear faces of the neighboring teeth (planes 3 and 4) the contacting surface of the opposite teeth (plane 5) and finally the lower limit of the implantation zone of the prosthesis (plane 6). This defines the real limits of the volume into which the prosthesis must be inserted (FIG. 10).

To avoid having to enter excessive data into the computer, the prosthesis is generated by adaptation of a standard tooth shape in the computer memory to fit into this volume.

As mentioned above, the operator first causes the theoretical tooth stored in the memory which is closest to the tooth to be fitted to appear on the screen (FIG. 11). By using a CAD/CAM package (Euclid: Geometric Transformation), and by controlling the cathode ray tube, the operator matches the form of the theoretical tooth to the previously determined volume or envelope. This adaptation is first made by moving the center of gravity of the standard tooth onto the center of gravity of the implantation site of the prosthesis (FIG. 12), then by deformation of the surfaces of the outline of the standard tooth, so that they are tangent to the planes limiting the volume of the previously determined envelope (FIG. 13).

The exterior surface of the prosthesis has thus been defined. The interior (lower) surface corresponds to that of the implantation site. The logic package (Euclid) then determines the actual volume of the prosthesis, taking into consideration the exterior surface previously defined, the shape of the implantation site, and finally, other factors such as the thickness of the cement film which will hold the prosthesis (FIG. 14). The combination of interior and exterior surfaces is effected by superposition of the implantation site on the lower limit of the standard tooth, as modified (FIG. 15).

The computer aided design system, such as Euclid and VAX, allows the transformation of the theoretical model into the actual model (FIG. 16). The results can be visualized according to predetermined views (FIG. 17). At this stage, visualization of the actual model of the prosthesis and its adjoining areas make it possible to verify the exact shape of the model and, if necessary, make modifications at particular points.

After the real model has thusly been determined, the CAD/CAM system controls the manufacture of the prosthesis or, depending upon the material utilized, of a casting into which the material for the prosthesis will be poured. FIG. 18 illustrates the program for manufacturing control of successive planes, as generated by Euclid. (FIGS. 19 and 20).

The process of the present invention thus has several principal stages which may be summarized as follows:

(a) one time creation of an optical pattern independently of the object itself and connected only to an interference phenomenon, either optical-optical or optical-electronic;

(b) immediate carrying out of an analog-digital conversion;

(c) determining the external and internal shape of the prosthesis solely by mathematical means within the computer, on the basis of CAD/CAM techniques, the computer having stored data defining standard shapes, such as the shape of the adult and baby teeth, which may be modified in accordance with the interference patterns derived from the particular patient.

It must be noted that nowhere in the process of the present invention is wax or resin used to make an imprint nor is there any manual adjustment of the prosthesis.

The process has been carried out successfully by the inventors to manufacture a prototype which functions perfectly and which allowed a dental prosthesis to be manufactured within 20 minutes.

It must of course be understood that, in particular, the process of the present invention makes use of a truly interferometric method. In a preferred embodiment, the interference patterns are not obtained by interference of a reference beam and a diffraction beam, but by interference between a grating which is not deformed and a luminous grating which is deformed by the zone being analyzed. It should be noted that it is not measurements of an object, but solely interference phenomena derived from the object which are utilized in the automatic manufacture of the prosthesis.

This interferometric method allows analog-digital conversion with the restricted financial means available in a, for example, dental office. The shape of the prosthesis is then derived strictly mathematically by a CAD/CAM system.

Further, the interferometric method allows the optical interference patterns to be obtained in a very short time, namely several microseconds (scanning at 5

MHz), data processing time (as opposed to other methods) readout time for the prosthesis (as opposed to other methods) readout time but shorter than the time required for the prosthesis to be financially viable.

We claim:

1. A method of creating an artificial organ for an organ site; scanning said organ site; processing said site data; and machining said site data; and

2. The method of step of creating

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turer by Euclid.

We claim:

1. A method of producing a prosthesis of an organ at a determined organ site, comprising the steps of:  
creating an interference pattern containing site data corresponding to a three-dimensional view of said organ site;  
scanning said interference pattern to produce digital site data;  
processing said digital site data to create machine tool data; and  
machining said prosthesis to fit said organ site directly under control of said machine tool data.
2. The method as set forth in claim 1, wherein said step of creating said interference pattern comprises the

steps of projecting a laser beam onto said organ site, thereby creating an object beam diffracted in accordance with said site, and projecting an undiffracted resonance beam to interfere with said object beam, thereby creating said interference pattern.

3. A method as set forth in claim 2, further comprising the step of recording the so-created interference pattern;

and wherein scanning said interference pattern comprises scanning a holograph.

4. A method as set forth in claim 1, wherein said creating an interference pattern comprises projecting a grating onto said organ site, thereby creating a deformed grating, and combining said deformed grating with an undeformed grating, thereby creating said interference pattern.

5. A method as set forth in claim 4, wherein scanning said interference pattern comprises scanning said pattern directly with a television camera.

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