This invention relates to a variable-reluctance electrical machine having a rotor which has a very low inertia about its axis.

On way of devising high-performance variable-reluctance machines is for the rotor teeth thereof to have a composite, magnetic and non-magnetic structure, whose mean magnetization intensity in a strong field is less than the saturation induction of the other magnetic parts of the machine. It results that only the teeth- and no other part of the machine- are saturated, which helps to localise strong fields to the places where they are most effective and makes it possible to control flux variations so that the sum of the fluxes modulated in the machine stays constant. In such machines, which form the subject of the Applicants' Canadian Patents No. 672,548 issued October 22, 1963 and No. 727247 issued February 1, 1966 and Applicants' Canadian Patent Application Ser. No. 943,400 filed October 20, 1965 and Ser. No. 960,980 filed May 20, 1966, the teeth form part of the machine rotor and the same forms a fairly large proportion of the magnetic circuit. This moving part of the magnetic circuit has a mass which is usually several **tens** of times greater than the mass of the teeth and therefore has considerable inertia which may make it difficult for rapid variations of angular velocity to occur.

The object of the invention is to provide variable-reluctance saturated-teeth machines similar to the general outline just given but with a rotor which has a much lower inertia about its axis than the rotors of the known machines.

According to the invention, the machine rotor shaft is rigidly connected mechanically just to the rotor teeth, the same taking the form of parallel magnetic laminations parallel to the shaft and being separated from one another by non-magnetic gaps so as to be saturated to the exclusion of every other part of the magnetic circuit; and the latter, which comprises all the operative ferromagnetic materials, is stationary except for the teeth and, with the windings and frame, forms the machine stator.

In one form of the invention, an electrical machine comprises: a rotor comprising: a shaft; a number of teeth made up of laminations parallel to the axis, preferably of alternate ferromagnetic and non-ferromagnetic material having a mean magnetization intensity (induction less field) in a strong magnetic field which is constant; and two-non-magnetic support members which retain the teeth in a radial position and rigidly secure the teeth to the shaft; and

a stator comprising two parallel symmetrical rings which are disposed opposite one another, each having tips made of a laminated ferromagnetic material and bearing appropriate windings; and a frame which closes the magnetic circuit outside the machine and in which the rotor shaft is mounted through the agency of plain or anti-friction bearings.

The radial teeth move in the air gaps bounded by the tip ends of the two oppositely disposed rings and transmit to the rotor the torque due to the magnetic fields which exist in the airgaps, the teeth offering little inertia in respect of variations of angular velocity.

The teeth are formed by laminations of ferromagnetic material and by laminations of insulating non-magnetic material, and each such lamination has at its base a widening which engages in the rotor support members and, by serving as shoulders, provides an anchorage which effectively opposes forces due to centrifugal force.

The teeth can be individual teeth formed by a stack of ferromagnetic laminae and insulating non-magnetic laminae with a high proportion of glass fibre, each ferromagnetic lamina being enveloped in the laminated insulant, so that the teeth have very good mechanical strength and the mean iron induction in a strong field is reduced by the non-magnetic laminae.

The teeth can also be formed by some parts of a ring formed by a multi-turn winding of two tapes or strips which are disposed one beside another and one of which is made of magnetic metal and the other of a fibrous non-magnetic insulant,, such winding being deformed subsequently to give parts which are alternately nearer and further from the center of the ring. The parts which are relatively far from from the center rotate between the stator tips and form the rotor teeth, whereas the parts which are relatively near the center rotate outside the stator field and have no effect.

According to another feature of the invention, each stator tip is formed by the connection between two arms of two groups of U-shaped laminations, preferably of grain-oriented magnetic metal, and when the machine operates the semi-circular part of the lamination groups mixes the modulated fluxes to provide a constant flux.

The invention will be better understood from the following description and accompanying drawings in which:

-Fig. 1 is a view in axial half-section of a three-phase synchronous motor according to the invention;

-Fig. 2 is a half-section of the machine shown in Fig. 1, looking from the right and along the section line II-II, so as to show the rotor teeth and stator tip ends;

-Fig. 3 is a section on the line III-III of Fig. 2, showing the arrangement of the stator tips;

-Fig. 4 is a view in axial half-section of a three-phase synchronous motor according to the invention wherein the rotor teeth are embodied by an appropriately deformed ring of metallic and insulating laminae; and,

-Fig. 5 is a partial section along the line V-V of Fig. 4.

The motor shown by way of example in the accompanying drawings is constructed in accordance with the principles herein before referred to of saturated-teeth variable-reluctance electrical machinery. This motor is a three-phase synchronous motor for operation on 50 or 60 cycles per second industrial current, and rotor inertiz must be so related to the forces applied to the teeth that the rotor reaches its synchronous speed in less than 0.01 second, so as to be startable without external mechanical drive.

The rotor 1 is formed by:

- a non-magnetic shaft 10 mounted in anti-friction bearings 11, 12;

-two metal support members 13, 14 rigidly secured to the shaft 10, and

-eight teeth 15 which are retained by the support members 13,14, Each tooth takes the form of a stack of 0.2 mm thick pure iron laminae 16 whose main surfaces extend parallel to the machine axis. Each lamina 16 is separated from the adjacent lamina by a 0.144 mm thick insulating layer 17, the insulant being a glass-fibre-loaded material which sticks strongly to the surface of the iron laminae. Each lamina has a base 30 which is wider than the tooth and which has two symmetrical shoulders 18 providing very good anchorage in circular grooves 19 in the inside surfaces of the support members 13, 14.

The stator 2 is formed by:

-trapezidal cross-section magnetic tips 20, 21 arranged in the form of two rings each comprising twenty four tips;

-forty-eight main windings 22 disposed on each tip, three consecutive main windings being energised by the three phases of a three-phase supply;

-two exciting windings 23 in the form of circular rings encircling the main winding assembly, and

-two extra-mild steel substantially symmetrical support members 24, 25 which bear the tips 20, 21 and close the magnetic circuit around the back of the exciting windings 23.

The tips 20, 21 are made of grain-oriented silicon steel laminations, the orientation of the grain in the tips extending parallel to the machine axis. The laminations are stacked to form a U-circuit by a continuous strip or tape being wound into an oblong winding and cut into two symmetrical sections. Each tip 20, 21 consists of two adjacent "back-to-back" arms of two U-circuits 26, 27 or 28, 29.

The two rings of tips are disposed symmetrically of the rotor plane and bound twenty four airgaps in which the eight teeth move. When the motor is running, the ampere turns of the exciting windings (or, where applicable, the action of a permanent magnet) produce in the airgaps a magnetic field which extends parallel to the machine shaft and which the main winding ampere-turns increase or reduce. The saturated teeth are urged by these magnetic field differences and, via the rotor support members 13, 14, apply a torque to the shaft to rotate the same.

Referring now to Figs. 4 and 5, the motor stator is the same as in Fig. 1, but the rotor teeth 35, although as in Fig. 1 formed by preferably pure iron ferromagnetic laminations separated from one another by non-magnetic insulating laminations formed by glass fibre enveloped in a thermosetting material, are constructed differently from Fig. 1. The rotor tooth system is devised from a single ferromagnetic strip or tape or the like 31 which is first wound around a cylinder together with a strip or tape or the like of glass fabric 32 to form a ring having an outer diameter from 5 to 20 per cent greater than the outer diameter of the finished rotor.

The resulting ring is then deformed, but not as far as the elastic limit of the metal plate 31, to form the rotor teeth. To this end, the ring parts between two consecutive teeth are pushed towards the center of the ring so as always to be outside the stator airgaps when the machine is assembled.

When shaping has been completed by means of appropriate equipment, a thermosetting material is injected into the glass fabric, whereafter the ring assembly, maintained in its final shape, is moulded at elevated temperature to form a non-deformable element. Such element is then formed with two circular grooves 33, 34 to receive the rotor support members 13, 14 which are rigidly secured to the machine shaft 10.

The main advantage of this feature is the cheapness of manufacturing the rotor, since manufacture and the positioning of the teeth cease to be separate operations.

The force acting per unit of tooth front area is expressed by the product of the mean magnetization intensity (or intrinsic induction) of the tooth in a strong field by the field difference between the airgap which the tooth is and the airgap which the tooth is leaving. In one machine according to this invention, the mean magnetization intensity is 1.25 tesla (weber per m^2), the effective mean field difference reaches 400,000 amperes per meter and so the force per area unit of the tooth front is 1.25 x 400,000 = 500,000 newtons per m^2. This force is applied to a tooth mass having a value equal to the mean density of the tooth multiplied by its mean length along a circumference around the machine axis. In the event, the mean density of the tooth is 5,550 kg/m^3 and the length is 0.03 meter, and so the tooth mass to which the force is applied is 5,550 x 0.03 = 167 kg; is 50 per cent is added to the figure for tooth inertia to cover the mass of the rotor support members and shaft; the figure for tooth mass becomes 167 + 83 = 250 kg. The acceleration applied to the rotor tooth is therefore approximately $\frac{500,000}{250}$ = 2,000 m. $sec.^{-2}$.

Since the mean peripheral velocity of the teeth when operating on 50 cycles per second is about 3 meters/second, the rotor will run up to this speed in $\frac{3}{2,000} = 0.0015$ second, and so the synchronous motor will start independently without any special facility (provided only that the immediate inertia of the driven masses outside the machine is not excessive).

The features described therefore lead to the construction of electrical machines - motor or alternators - wherein the ratio of the useful torque to the inertia of the rotor is much lower than in conventional machines, with the result of technical and economic advantages, since the performances of many mechanical devices can be improved by the large variations in angular velocity which the invention can provide.