ROTATING MACHINE DRIVES SUPPORTED BY SUPERVISORY SYSTEM WITH FAULT DIAGNOSIS

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***Abstract* – In this work is presented the survey of strategy and efficiency of fault diagnoses in rotating machines in steady state using database and supervisory systems. In this survey was simulated the rotating machine mathematic model, which data will be used as reference for a real process in the supervision, what the interesting variables will be acquired by means sensors using LabVIEW interface. These data are recorded in database build in SQL Server that compared shows an analysis of the founded faults.**

***Keywords* – Drives, , Rotating Machine, Supervisory Sistem, Torque, Vectorial Control.**

I. INTRODUCTION – DRIVE MONITORING

In a monitoring of operational conditions of rotating machines in steady-state can be used supervisory systems that show to the maintenance accurate and reliable information about faults and anomalies before happen serious damages to the machine. These events are registered and stored in a database to help the making-decision and preventive or predictive maintenance actions and improve the performance and efficiency of rotating machines.

In the database are storage the normal operation machine parameters acquired by sensors, that identifying faults, beside the results of simulation of the mathematic model of this machine.

With these data are made comparisons, that is, an analysis presenting the deviations, diagnosing and verifying faults evolution.

This work present the survey about the rotating machine drives using supervisory systems and with support of a computational system developed in SQL Server and LabVIEW can be achieved the fault diagnosis.

II. VECTORIAL CONTROL OF ROTATING MACHINES

The vectorial control in rotating machine drives can guarantee that the magnetomotive force (mmf) produced by armature current is in quadrature with the flux produced by machine stator. In this case the control is facilitated because the armature and stator fields are detached so the machine model becomes similar to the DC machine model. Both, flux and mmf, remains stationary and the electromagnetic torque produced and developed by the machine depends linearly of the armature current in according to (1).

$$T_{em} = k_T i_a \tag{1}$$

Where:

T_{em} = Electromagnetic torque.
k_T = Machine torque constant.
i_a = Armature current.

To verify the performance of this control was simulated a disturbance represented for a step function by means Processing Power Unit (PPU), illustrated in Fig. 1, which keeps the current amarmature vector $\vec{i}_s(t)$ 90º ahead to rotor field vector $\vec{B}_r(t)$ towards rotation.

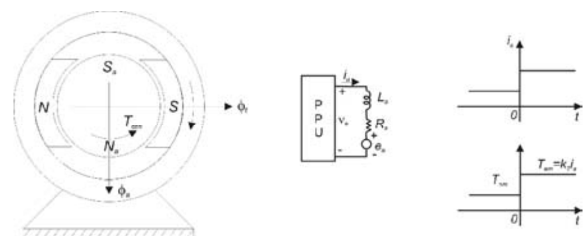


Fig 1. DC motor drive.

A step changing in the torque requires a step changing in rotor current of machine vector controlled. Therefore, is used a set of orthogonal axes windings d and q producing the same stator mmf of three windings, each a N_s coils sinousidally distributed, with currents i_a, i_b and i_c and the mmf resulting $\vec{F}_s(t)$ can be produced by the set of orthogonal axes windings, each distributed with $\sqrt{3/2}N_S$ coils. Thus, the set of axes d and q can be in any arbitrary angle related to axe a (stator axe) illustrated in Fig. 2.

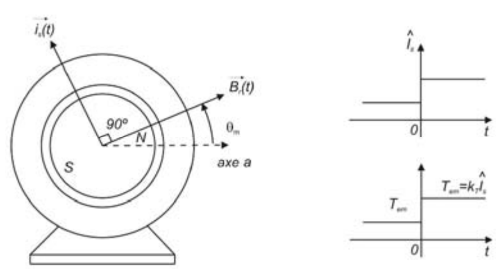


Fig 2. Motor drives with controlled current.

Intend to keep the mmf and flux density distribuition the currents of this two windings should be i_{sd} and i_{sq}. The axe d are aligned with the rotor flux space vector so that the linkage machine flux in the axe q is null.

III. MACHINE MATHEMATIC MODEL SIMULATION

Based on control vector theory for rotating machines was developed and simulated the mathematic model, which block diagram is illustrated in Fig. 3.

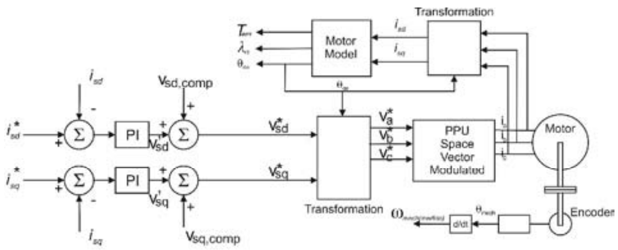


Fig. 3. Simulation diagram.

Where:

i_{sd}^{*}, i_{sq}^{*} = Stator current reference in d and q axes.

i_{sd}, i_{sq} = Stator current in d and q axes.

$V_{sd}^{'}$, $V_{sq}^{'}$ = Stator voltage reference in d and q axes.

$V_{sd,comp}$, $V_{sq,comp}$ = Stator compensation voltage in d and q axes.

V_a^*, V_b^*, V_c^* = Input voltage in phases a, b and c.

i_a, i_b, i_c = Current in phases a, b and c.

λ_{rd} = Rotor flux in d axe.

θ_{da} = Angle between d and a axes.

$\omega_{mech(medido)}$ = Mechanical speed.

θ_{mech} = Mechanical angle.

The parameters used to simulation are presented in Table I.

TABLE I
Simulation Parameter.

Rs	Rr	Xls	Xlr	Xm	Jeq	p
1.77	1.34	5.25	4.57	139	0.025	4.0

Onde:

Rs = Stator resistence.
Rr = Rotor resistence.
Xls = Stator reactance.
Xlr = Rotor reactance.
Xm = Magnetization reactance.
Jeq = Equivalent inertia moment.
p = Poles number.

In Fig. 4 and Fig. 5 are illustrated the speed and torque waveforms obtained from the proposed system simulation. Is noticed that for each change in the load torque has a changing in the mechanical speed of machine. Also can noticed that control system proposed take the mechanical speed its steady-state value with precision and a short settling time.

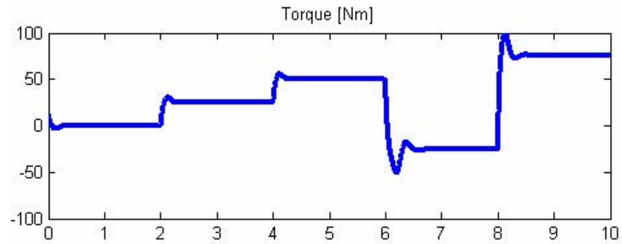


Fig. 4. Simulated load torque.

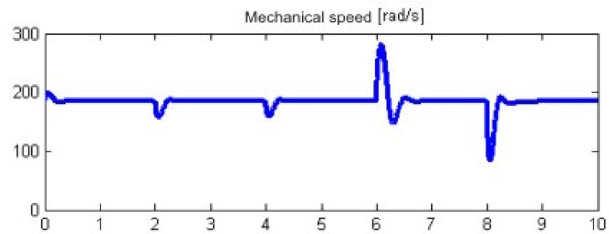
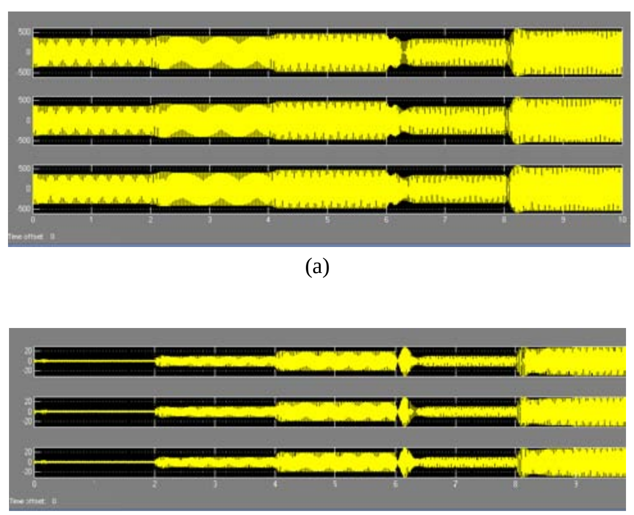


Fig. 5. Simulated mechanical speed.

In Fig. 6 was verified that as voltage as stator currents suffer the effects of torque changing. As well as the speed rapidly was taken to the steady-state condition by the vectorial control action, the voltage and currents waveforms was also taken to the steady condition with high speed and accuracy.



(a)

(b)

Fig. 6. Simulated machine three-phase waveforms. (a) Voltages and (b) Currents.

IV. SENSORS

The speed sensor is presented in Fig. 7and uses the serial transmission with output complementary for sinusoidal signal, being that amplitude of this signals should be situated in range of 0.8 to 1.25 V_{pp} (peak-peak) decreasing with the increasing of rotating speed. The operation cutoff frequency of this sensor must be situated above 200 kHz.

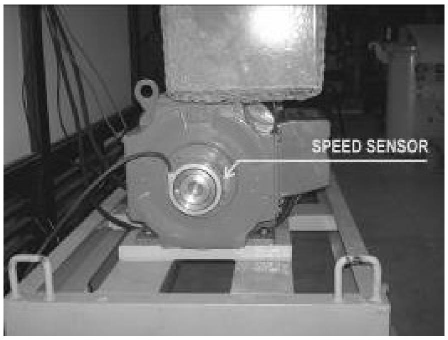


Fig. 7. Speed sensor.

The torque monitoring uses an analog sensor illustrated in Fig. 8 and the signal ranges of 500 mV to 4.5 V, parameter required by DAQ board, just a fourth order low-pass filter.

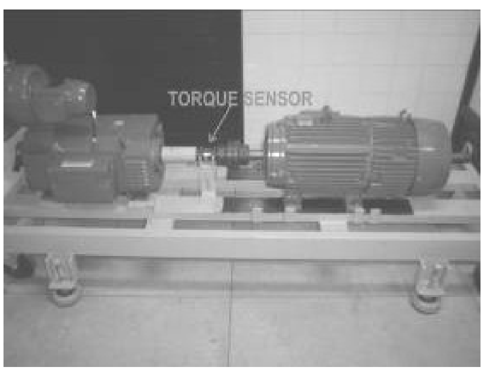


Fig. 8 Torque sensor.

Current and voltage sensors are illustrated in Fig. 9, in their respective conditioning board. The current sensors can obtain measures until 50 A and voltage sensor to 400 V.

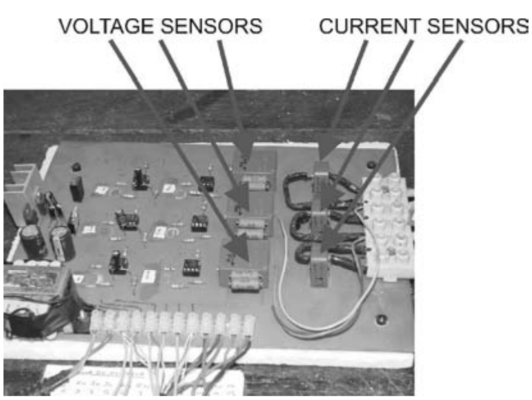


Fig. 9. Voltage and current conditioning board.

V. EXPERIMENTAL BENCH

The experimental validation of diagnosis methodology was carried out in a laboratory bench. This is constituted by a elementary machine (DC motor) coupled by means a torque sensor, to a rotating machine that can be a motor or generator (see Fig. 10). The elementary machine is droved by a AC-DC converter reproduces in it axe torque an speed simulating the behavior of any resistant force, like a pump, carried track, etc. Thus, when the elementary machine is coupled a electric machine, the bench is able to simulate the operation of the motor ahead of any industrial load. A variable speed drive is used to drives the electrical machine supplying this a vectorial control and is illustrated in Fig. 11.

Fig. 10. Elementary machine with generator coupled to axe.

Fig. 11. Variable speed drive with vectorial control and AC-DC converter.

VI. DATA ACQUISITION

The methodology to be used as to verify deformities in stator windings, distance between poles and rotor or other phenomena that reflects into machine magnetic circuit, will be made by correlation between statorical current harmonic composition and information of sensors distributed in machine pieces.

Information obtained by sensors will be conditioned and sent to a DAQ board and later treated in supervisory system.

VII. DATABASES

Databases join a managed friendly interface, a set of routines that include functionalities required to change frequently this interface. All functionalities can be possible due to data warehouse and to Online Analytical Processing (OLAP), that are used in many companies to extract an analyze the database useful information to making-decision. With all this resources the database technology, now is used for industrial and production process control.

To keep large databases shared are used Database Management System (DBMS). It's treat of a software that adds functions of definition, recovering, and changing data, which can be several types like object-oriented or object-relational, being this last dominant nowadays in the market, and which will be used in this work.

A. Database Management System (DBMS)

Database Management System (DBMS) is architectures that have been following trends similar the one of architectures computer systems. In other words, before to the concept of personal computers (PC) and workstations all data processing were made in mainframes to later be sent for exhibition in others terminals.

In Fig. 12 are illustrated the physical scheme of a central DBMS. However, in a gradual way DBMS architectures started to explore power available processing on the user's side becoming a structure client-server.

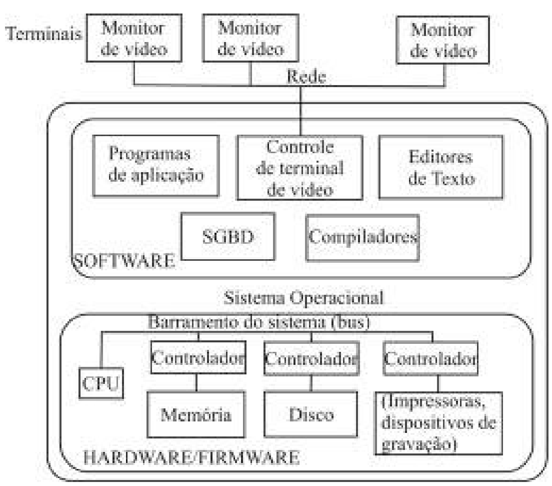


Fig. 12. DBMS physical scheme.

Client-server architecture was developed to work in computational environments, which a large number of PC's, workstations, server, printers and database server, Web server and others equipments are connected network. Thus, defining specialized Server with specific functionalities. In Fig. 13 are showed the architecture client-server in logic level and physical structure.

B. Entity Relational Database Model

Entity versus Relational (ER) is a formal model that presents database proprieties, which consists in many tables that's communicates amongst themselves through relationships, according can be observed in Fig 14 by means primary and foreigners keys

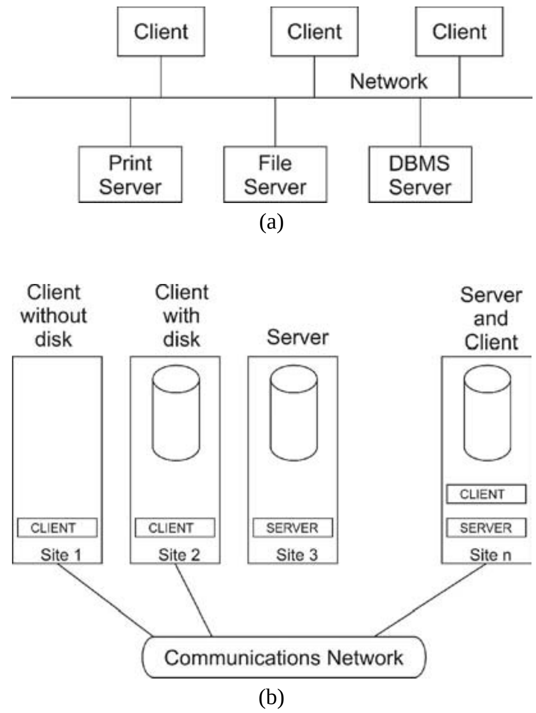


Fig. 13. Client-server architecture. (a) Logic level and (b) Physical structure.

Tables contain system securities data, for examples, user's profile, temporary storing data, where data acquired by sensors are treated during operation machine. There is the table which is stored permanents data, for example, measurements obtained during mathematic model simulation.

The table called *Evento* cannot relationship with another one and their function is register periodic events to be collected by the system.

The choice of this database, SQL Server 2000, is due to stability that provides safety and reliability to data system, besides treating a relational database destined to be compatible with applications that presents client-server architecture, where database is resident in a mainframe, which information are shared by several users that performs applications in their local computers, or clients.

Data integrity is guaranteed by DBMS, because are imposed applicable controls to all users with relation to the recorded and recovered information, therefore client-server architecture reduces considerably the network traffic, because attends only users with requested data via SQL. This way making possible that maintenance tasks , like backup and restoration becoming easy to be performed, since data stored in only one place.

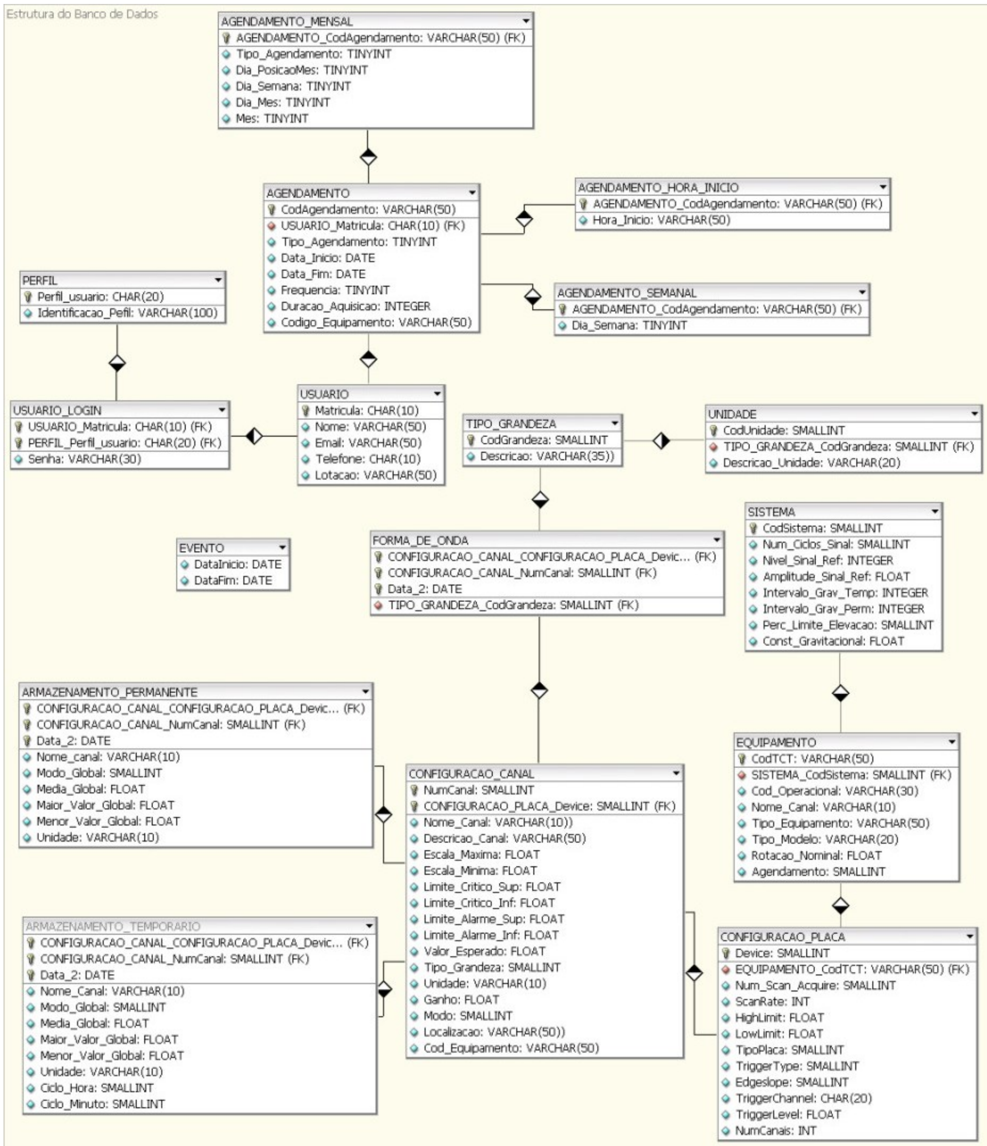


Fig. 14. Relational database

VIII. SUPERVISORY SYSTEM AND FAULT DIAGNOSIS

In Fig. 15 is presented supervisory system screen, which will be available as much acquired data as obtained results in mathematic model simulation. The system was developed in LabVIEW, which is responsible by the following functions, such, users managing, DAQ setting, recording events in database, displaying acquired signals, turn available data for clients and elaborating reports.

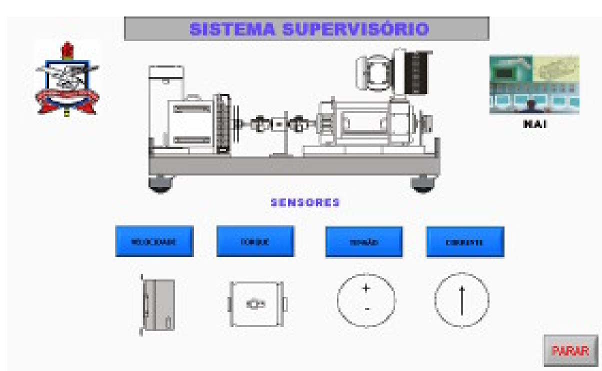


Fig. 15. Supervisory system screen.

A. Fault Diagnosis

With stored data in database is possible make a diagnosis comparing the waveforms acquired by sensors installed in machine and carry out a comparison with parameter acquired in mathematic model simulation.

In Fig. 16 are illustrated load torque changes and correspondent speed changes. Can also be observed that waveforms of reconstituted signal from database are similar to the one acquired by simulation.

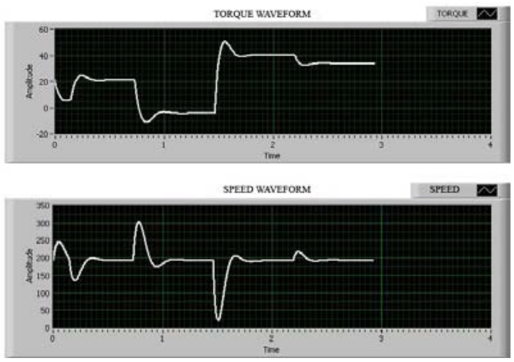


Fig. 16. torque and speed waveforms.

In Fig. 17 are illustrated three-phase voltage waveforms and the effects that changing in load torque produces in the voltage stator of machine. And in Fig. 18 are illustrated three-phase current waveforms to the same changes presented in Fig. 16.

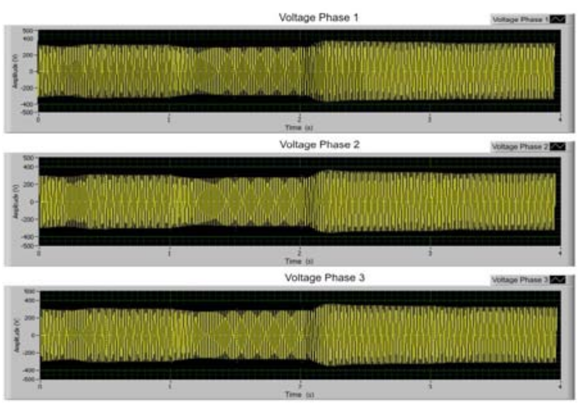


Fig. 17. Three-phase voltage waveforms.

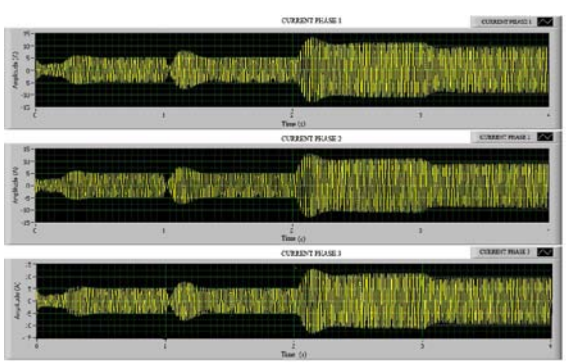


Fig. 18. Three-phase current waveforms.

The current verifying must correspond a change in torque. When this doesn't occur are diagnoses problems in coil windings or in connections. In similar way, a pulsing torque or an undulation can indicate the displacement coils.

IX. CONCLUSION

It was developed a vector control applied to rotating machines in an experimental bench that permitted to verifying the proposed methodology to diagnosis faults. The vector control was implemented using a variable speed drive

With this diagnosis methodology joined supervisory system and relational database have been demonstrated that this one is efficient to carrying out prediction and diagnosis faults. Moreover, becoming possible to increase operational reliability of machine, reduces costs with maintenance and avoid nonprogrammed interruptions in processes.

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