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Examination of Plasma Disruption in Tokamak using Hilbert Transform

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ABSTRACT: A Tokamak is a device that uses a powerful magnetic field which confines plasma in the shape of a torus to produce electricity. At the necessarily large toroidal currents the tokamak concept suffers from a fundamental problem of stability. The nonlinear evolution of magnetohydrodynamic instabilities leads to a dramatic quench of the plasma current within milliseconds. To avoid these problems, the signals h-alpha, plasma current, soft x-rays have to be analyzed. By applying the Hilbert Transform to these signals and finding their statistical parameters we identified the error signal which is causing the disruption.

KEYWORDS: Tokamak, Disruptions, MagnetoHydroDynamic instabilities, Hilbert transform.

I.INTRODUCTION

A tokamak is a device that uses a powerful magnetic field which confines plasma in the shape of a torus to produce power. Achieving stable plasma equilibrium requires magnetic field lines which moves around the torus to keep it in helical shape. This helical field is generated by adding a toroidal field which will travel around the torus in circles and a poloidal field which will travel in circles orthogonal to the toroidal field. In a tokamak, the toroidal field is produced by electromagnets that surround the torus, and the poloidal field is the produced by toroidal electric current that flows inside the plasma. This is the current that is induced inside the plasma with a second set of electromagnets. The tokamak is one of several types of magnetic confinement devices, and is being used to contain the hot plasma that is needed for producing controlled thermonuclear fusion power. It is the leading candidate for a practical fusion reactor. No solid material could withstand the extreme high temperature of the plasma so the magnetic fields are used for confinement.

Positively and negatively charged ions and negatively charged electrons in a fusion are at very high temperatures and have correspondingly large velocities. To maintain the fusion process, particles from the hot plasma must be confined in the central region else the plasma will rapidly cool. The charged particles in a magnetic field experience a Lorentz force and follow helical paths along the field lines in the magnetic confinement fusion devices.

For the toroidal plasma to be effectively confined by a magnetic field, there must be a twist to the field lines. Then there won't be any longer flux tubes that simply encircle the axis except flux surfaces if there is sufficient symmetry in the twist. Some of the plasma in a flux surface will be on the outside of the torus and will drift to other flux surfaces farther from the round hub of the torus. Different bits of the plasma in the flux surface will be on the inside. Since some of the outward drift is compensated by an inward drift on same flux surface, there is a plainly visible harmony with greatly enhanced confinement. Another approach to take a gander at the impact of curving the field lines is that the electric field between the top and the base of the torus, which tends to bring about the outward float, is shorted out in light of the fact that there are presently field lines associating the top to the base. When the problem is considered even more closely, the need for a vertical component of the magnetic field emerges. The Lorentz drive of the toroidal plasma current in the vertical field gives the inward force that holds the plasma torus in equilibrium.

At the necessarily large toroidal currents, the tokamak concept suffers from a fundamental problem of stability. The nonlinear evolution of magnetohydrodynamical instabilities leads to a dramatic quench of the plasma current within milliseconds

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and the runaway electrons are created and finally, a global loss of confinement happens. At that point, very intense radiation is inflicted on small areas. This phenomenon is called a major disruption. The occurrence of major disruptions in running tokamaks has always been rather high, of the order of a few percent of the aggregate quantities of the shots. In as of now worked tokamaks, the harm is frequently expansive but rarely dramatic. In the tokamak, it is expected that the occurrence of a limited number of real interruptions will absolutely harm the chamber with no probability to re-establish the device.

H-alpha (Hα) is a dark red obvious ghastly line in the Balmer arrangement with a wavelength of 656.28 nm, it happens when a hydrogen electron tumbles from its third to second most minimal vitality level. H-alpha light is critical to stargazers as it is discharged by numerous outflow nebulae and can be utilised to watch highlights in the Sun's climate, including sun based prominences and furthermore for the tokamak. X–rays having a wavelength of 4å or above, have a lesser recurrence and consequently lesser vitality. They are called delicate X – beams because of their low infiltrating power. They are created in a nearly low potential contrast. Plasma current is the stream of charged particles around the tokamak's doughnut-shaped formed vessel (rather than the arbitrary development of the hot plasma particles). It is initiated similarly that a transformer works. The essential curl is a substantial electromagnetic loop in the focal point of the doughnut (its post), and when some changing current courses through this loop, the plasma itself goes about as an optional winding and has an expansive current prompted in it.

Plasma current is vital to the operation of the tokamak in two ways. Firstly, the instigated current begins the plasma off and gives it its underlying warmth, in an impact known as ohmic warming. Besides the current makes a poloidal attractive field, which joins with the toroidal field to make an attractive field with a wind. This curve is crucial for binding the hot plasma surging around the tokamak, on the grounds that without it the particles would float outwards and crash into the external dividers of the vessel.

Strictly speaking, the Hilbert transform is not a transform in this sense. Firstly, the result of a Hilbert transform is not equivalent to the original signal, rather it is a completely different signal. Secondly, the Hilbert transform does not involve a domain change, i.e., the Hilbert transform of a signal x (t) is another signal denoted by in the same domain (i.e. time domain). Obviously performing the Hilbert transform on a signal is equivalent to a 90° phase shift in all its frequency components. Therefore, the only change that the Hilbert transform performs on a signal is it will change the phase of a signal. The amplitude of the frequency components of the signal do not change by performing the Hilbert-transform. On the other hand, by performing the Hilbert transform which changes cosines into sines, the Hilbert transform of a signal x(t) is orthogonal to x(t). Also, since the Hilbert transform introduces a 90° phase shift, carrying it out twice causes a 180° phase shift, which may cause a sign reversal of the original signal.

By using Hilbert transform we will be able to create an analytic signal based on some original real-valued signal and in the communications world, we can use the analytic signal to easily and accurately compute the instantaneous magnitude of the original real-valued signal. The resultant analytic complex signal is provided by the Hilbert transform of a 1D/real signal. The analytic signal representation gives us the information about the local structure of the signal.

II. BLOCK DIAGRAM

The Fig 1 shows the block diagram of the process. The Hilbert transform was applied on the acquired signals and the statistical parameters are calculated for the analysis.

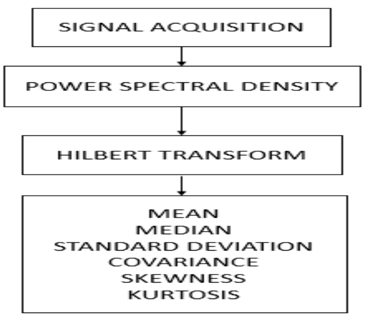

Fig 1: Block Diagram

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i) Signal Acquisition and Processing

Signal processing is a technology that includes the crucial hypothesis, applications, calculations, and usage of preparing or moving data contained in a wide range of physical, typical, or dynamic arrangements extensively assigned as signals. It utilizes mathematical, statistical, computational, heuristic, and linguistic representations, formalisms, and techniques for representation, modeling, investigation, amalgamation, revelation, recuperation, detecting, procurement, extraction, learning, security or forensics. Here we are acquiring the signals from the tokamak and applying the Hilbert Transform to find out the error signal.

ii) Spectral Domain Analysis

The power spectrum of a time series describes the distribution of a power into frequency components composing that signal. According to Fourier analysis, any physical signal can be decomposed into several discrete frequencies or a spectrum of frequencies over a continuous range. The statistical average of a certain signal or sort of signal when analyzed in frequency content is called spectrum. When the energy of the signal is concentrated around a finite time interval, especially if its total energy is finite, one may compute the energy spectral density.

Iii) Hilbert Transform

Many application measurements result in a time signal containing a rapidly oscillating component. The amplitude of the oscillation varies slowly with time, and the shape of the slow time variation is called the envelope. The envelope often contains important information about the signal. By using the Hilbert transform, the rapid oscillations can be removed from the signal to produce a direct representation of the envelope alone.

iv) Statistical Parameters

a) Mean and Median: When working with a large set of data, it will be useful to represent the entire data set with a single value that describes the middle or average value of the entire set. In statistics, that single value is called the central tendency and mean, median and mode are all ways to describe it.

b) Standard Deviation: A quantity expressing by how much the members of a group differ from the mean value for the group.

c) Covariance: The mean value of the product of the deviations of two variates from their respective means.

d) Skewness: is the measure of symmetry, or more precisely, the lack of symmetry. A distribution, or data set, is symmetric if it looks the same to the left and right of the center point.

e) Kurtosis: is the measure of whether the data are peaked or flat relative to a normal distribution.

III.ALGORITHM

Step 1: Take one file as input signal from input directory.

Step 2: Open the file using 'fopen' command i.e. fid=fopen(file,'r').

Step 3: Then read the binary data from file by using 'fread' command i.e. fread(fid).

Step 4: Initialize the sampling frequency and then take number of total samples.

Step 5: P=nextpower2(A) returns the smallest power of two that is greater than or equal to the absolute value of A.

Step 6: Y=fft(X,n) returns the n-point DFT. fft(X) is equivalent to fft(X,n) where n is the size of X in the first nonsingleton dimension.

Step 7: After that plot, the amplitude spectrum.

Step 8: To compute the (absolute) spectral powers in the above eight frequency bands, PSD of the input signal needs to be estimated. The PSD of a signal describes the distribution of the signal's total average power over frequency. In this paper, the spectral power of a signal in a frequency band is computed as the logarithm of the sum of the PSD coefficients within that frequency band.

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Step 9: Hilbert transform enables us to create an analytic signal based on some original real-valued signal.

Step 10: X = HILBERT(Xr) computes the so-called discrete-time analytic signal

Step 11: X = Xr + i*Xi such that Xi is the Hilbert transform of real vector Xr.

Step 12: If the input Xr is complex, then only the real part is used i.e. Xr=real(Xr).

Step 13: Now calculate the statistical parameters like Mean, Median, Standard deviation, Covariance, Skewness and Kurtosis by using the formulas.

TABLE 1: Classification of the signals

Shots	**Signals**		
	H-alpha	**Plasma Current**	**Soft X-Ray**
Shot #1	22192	22192	22192
Shot #2	22229	22229	22229
Shot #3	23886	23886	23886
Shot #4	23889	23889	23889
Shot #5	26075	26075	26075

TABLE 2: Parameters of H alpha Signal

Parameters	**Shot 1**	**Shot 2**	**Shot 3**	**Shot 4**	**Shot 5**
Mean	166.139	166.965	167	166.919	165.008
Median	164.663	165.192	165.515	164.916	163.757
Standard Deviation	7.1017	7.0618	7.1066	7.1078	7.0859
Covariance	50.4348	49.8685	50.5036	50.5201	50.2095
Skewness	23.51	21.7135	22.6624	22.7405	23.6676
Kurtosis	355.014	306.521	338.104	339.126	356.052

TABLE 3: Parameters of Plasma Current Signal

Parameters	**Shot 1**	**Shot 2**	**Shot 3**	**Shot 4**	**Shot 5**
Mean	143.4308	144.248	144.2986	144.205	142.564
Median	144.103	145.0354	145.0601	144.894	143.005
Standard Deviation	7.0599	7.0635	7.067	7.0722	7.00723
Covariance	49.8424	49.8931	49.9426	50.0156	50.017
Skewness	32.7269	31.0244	32.3148	33.9579	34.8672
Kurtosis	846.1515	754.9437	829.5732	939.378	910.942

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TABLE 4: Parameters of Soft X-ray Signal

Parameters	Shot 1	Shot 2	Shot 3	Shot 4	Shot 5
Mean	166.1387	166.9534	166.9568	166.885	164.997
Median	164.6627	164.9238	165.0741	165.108	163.611
Standard Deviation	7.1017	7.1082	7.0958	7.0978	7.0613
Covariance	50.4348	50.5268	50.3499	50.3782	49.8624
Skewness	23.5188	22.7028	22.3038	22.216	23.0685
Kurtosis	355.0136	332.0746	320.8974	320.435	337.887

IV. RESULT AND DISCUSSION

We have taken few signals like H-alpha, Plasma Current and Soft X-rays which are obtained from the tokamak during power generation. These Signals are taken from various shots which are signified as shot 1,2,3,4 and 5 where the shot 2 has the error signal (these are the signals which damage the vessel of the tokamak and are need to be found out before they cause some damage) and the remaining are the correct signals. The signals are classified as error signals due to the magnetohydrodynamic instabilities or if so any unknown causes which arise inside the tokamak. From the experiments done in matlab Software by writing the matlab code in the editor window by following the steps written in the above algorithm. We have found the power spectrum and by applying Hilbert Transform we have inferred some results where the error signal shows the variation in the statistical parameters when calculated and compared with the original signals.

V. CONCLUSION

To analyse the disruptions in H-Alpha, Plasma Current, Soft Ray Signals from the Tokamak we took various reference signals (i.e. 4 correct signals and 1 error signal). From these Signals the Standard parameters like Mean, Median, Skewness, Kurtosis, Standard Deviation, and Covariance are found out and these parameters of the correct signals are compared with the error signal and are plotted on graphs. By using Hilbert Transform we can conclude that to find out the error signal the most suitable parameters are Covariance, Standard Deviation, Skewness and Kurtosis from the tables 2, 3 and 4.

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