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LOCALIZATION AND IDENTIFICATION OF DAMAGEOF CANTILEVER BEAM USING MODAL INDICSAND FUZZY-KSOM MODEL

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ABSTRACT

In the presentwork finite element method and fuzzy-KSOM hybrid technique are used for localization of damagepresent in form of cracks in the cantilever beam. The presence of cracks in the beam like structures is a serious threat to the performance as well as integrity of structures and itschange the modal indics e.g. natural frequencies and mode shapes of the structures.The glass fiber reinforced epoxy compositeis engaged in the present investigation due to its advantageous features, such as higher damage tolerance capability, improved fatigue resistance, high stiffness and strength-to-weight ratios compared with the metallic structures. The finite element analysis has been performed on the ANSYS software to establish the relation between the change in modal characteristics for the cracked and not-cracked composite beam. These changes in modal characteristics (first three relative natural frequencies, first three average relative mode shape difference)are used as input parameters to the fuzzy segment of the hybrid model and relative crack depths and crack locations are the output parameters of fuzzy model. The first three relative natural frequencies, first three average relative mode shape difference and the outputs from the fuzzy model are used as inputs to the KSOMsegment of the hybrid model and final crack depths and locations are the outputs of hybrid model. The modal characteristics are used to formulate a series of fuzzy rules and training patterns for the fuzzy and KSOM. The results obtained from proposed model isauthenticated by experimental analysis results from the developed experimental setup.

Keywords: Ansys, Crack, Fuzzy, Mode shapes, Natural frequency, KSOM.

I. INTRODUCTION

The study of the damage present in the beam like dynamic structures is an important not only for intregity structural systems but also leading the safe operation. Some structures such aslarge bridges are required to be continuously considered to detect possible damages in form of cracks to make sureabout the uninterrupted service. The identification of cracklocations and depths has been recognized as an “inverseproblem”. Nowadays, cracks are generally beingdetected by non-destructive testing methods such as ultrasonic testing, X-ray, etc.. These methods are costlyand timeconsuming specially for long components suchas railway tracks and pipelines. The paper provides a viable relationship between the modal natural frequency and mode shape at the different crack depth and location.

A review paper to study and compare several damage detection methodologies based on natural frequencies, modal strain energy and modal curvature analysis of a damaged Euler–Bernoulli beam has been presented by Dessi and Camerlengo [1]. They have divided all selected techniques into two classes: one includes techniques that require data from literatures for estimating structural changes due to damage; the second category contains the modified Laplacian operator and the fractal dimension. A multiple damage detection method based on Wavelet Transform (WT) and Teager Energy Operator (TEO) of beams has been described by Cao et al. [2]. The WT & TEO based curvature mode shape structures provide greater resistance to noise and more sensitivity to damage in comparison with the conventional curvature mode shape. A composite matrix cracking model is implemented in a thin-walled hollow circular cantilever beam using an effective stiffness approach by Pawar et al. [3]. Carr and Chapetti [4] have studied the influence of a surface fatigue crack on the vibration characteristics of T-welded plates and the results are compared to the control of machined through thickness cuts to the dynamic response of cantilever beams. They have analyzed the influence of fatigue cracks growth on the natural frequencies and compared to experimental data with two and three dimensions results of numerical modeling.

Multi Layers Perceptron (MLP) and Self Organizing Map (SOM) neural network based classifier for prognosis of fault of three phase induction motor and evaluated the performance of classifiers have been developed by Ghate and Dudul [5]. The different number of learning rules and transfer functions has investigated for different number of hidden layers. The simple statistical parameters used as input feature space and principal component analysis are used for reduction of input dimensionality. The effects of the crack location and depth and the fiber volume fraction and orientation of the fiber on the natural frequencies and mode shapes of the beam are explored. Two Damage identification algorithms are established for assessment of damage using modal test data which are similar in concept to the subspace rotation algorithm or best feasible modal analysis method by Hu et al. [6]. Moreover, a quadratic programming model is set up the two methodologies to damage assessments. Zhang et al. [7] have suggested a fault identificationtechnique on bearing,which is based on adaptive Neuro fuzzy inference system (ANFIS) and multiple scale entropy to measure the nonlinearity in a bearing system. They have performed experiments on electrical motor bearing with three different fault categories and got the results of the experiments, ithas been used to design and train the ANFIS system for fault measurement.A health monitoring of the cantilever beam containing transverse surface crack using neural network techniques has been developed by Suresh et al. [8]. They have calculated modal frequency parameters for different crack locations and depths using analytical method and these modal parameters are used to train the neural network to detect the damage severity and intensity.Zhu et al. [9] have proposed an ANFIS and integrated wavelet real-time filtering algorithm based helicopter structural damage identification method when the frequency and magnitude of harmonic excitation are constant. They have found that proposed integrated method can be effectively utilized for identifications of several unknown damages and small damages of structures and also it can be used to recognize both the time and the location when the structural damage occurs unpredictably.

In the present paper, a computational technique has been adapted for detection of cracks. Finite element analysis has been performed to find the change in the dynamic response of a cracked and non- cracked cantilever composite beam. The experimental investigation has been performed for authentication of FEA and hybrid controller results. An intelligentmethod, based on hybrid fuzzy-KSOM controller has been designed and trained with aggregated data sets of FEA and experimental analysis results, which is used to forecast the damage severity and its intensity.

II. FINITE ELEMENT ANALYSIS

The finite element analysis is carried out for find out modal parameters ofmultiple cracked cantilever composite beam(shown in fig1) at different crack depths and crack locations. The following dimentions of beam and cracks orientation are taken in the account:

Length of the Beam (L) = 800mm; Width of the beam (W) = 50mm; Thickness of the Beam (H) = 6mm

Relative crack depth (ψ_1=a_1/H) = Varies from 0.0833 to 0.5;

Relative crack depth (ψ_2=a_2/H) = Varies from 0.0.833 to 0.5;

Relative crack location (β_1=L_1/L) = Varies from 0.625 to 0.875;

Relative crack location (β_2=L_2/L) = Varies from 0.125 to 0.9375;

The individual material properties of the fiber (glass) and matrix (epoxy) are depicted in table 1.

Table 1 Material properties of Glass fiber- reinforced epoxy composite

	Fiber(Glass)	Matrix (Epoxy)
Elastic Modulus (Gpa)	E_f = 72.4	E_m = 3.45
Rigidity Modulus (Gpa)	G_f = 29.67	G_m = 1.277
Poisson's Ratio	υ_f = 0.22	υ_m = 0.35
Mass Density (gm-cm^{-3})	ρ_f = 2.6	ρ_m = 1.2

The finite element analysis is performed on cracked cantilever beam for getting the dynamic response of a vibrating structure. The natural frequencies and mode shapes are important vibration parameters for designing a structure system under dynamic loading conditions. The finite element analysis is done by using the finite element software ANSYS in the frequency domain and obtain natural frequencies, and mode shapes.

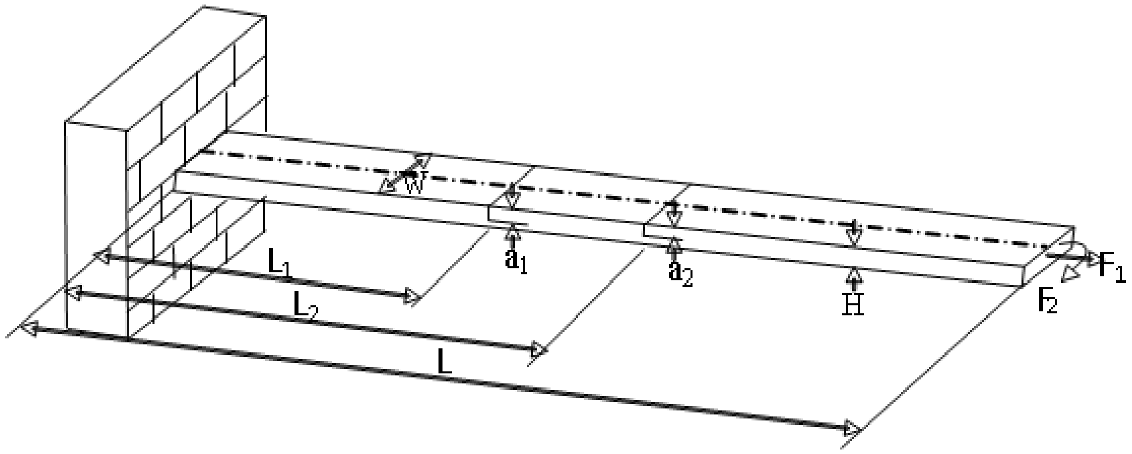

Fig. 1 Geometry Cantilever beam with multiple cracks

A higher order 3-D, 8 node element (Specified as SOLSH190 in ANSYS) having three degrees of freedom at each node: translations in the nodal x, y, and z directions was selected and used throughout the analysis. Each node has three degrees of freedom, making a total twenty four degrees of freedom per element. The layers, stacking in ANSYS shown in fig2. The results of the numerical analysis for the first three mode shapes for un-cracked and cracked beam (ψ_1=0.166, ψ_2=0.5 and β_1=0.25, β_2=0.5) are shown in the fig 3.

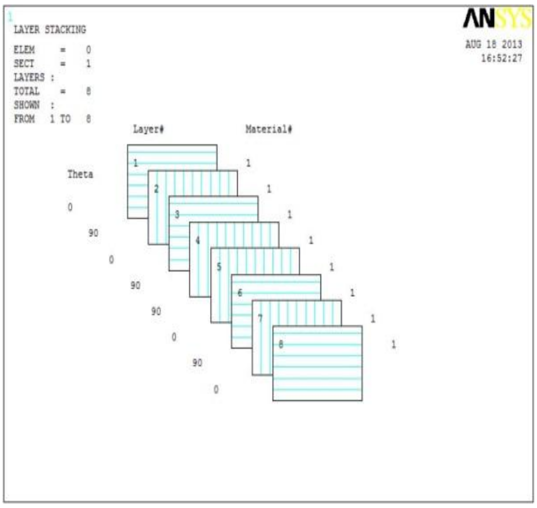

Fig. 2 Layers Stacking in ANSYS

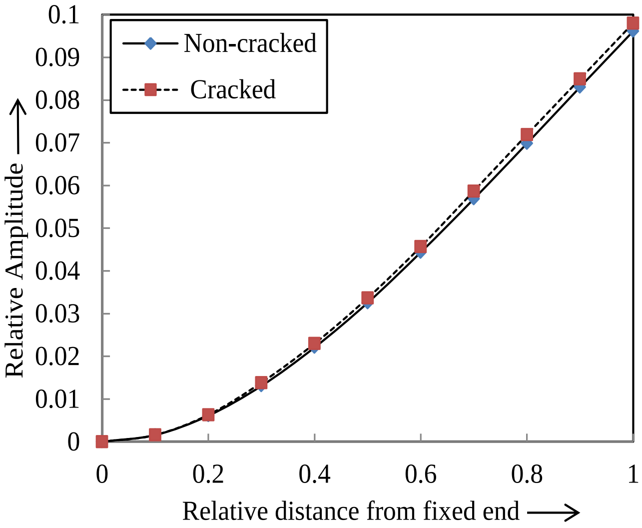

Fig. 3a. Relative Amplitude vs. Relative distance from fixed end (1st mode of vibration)

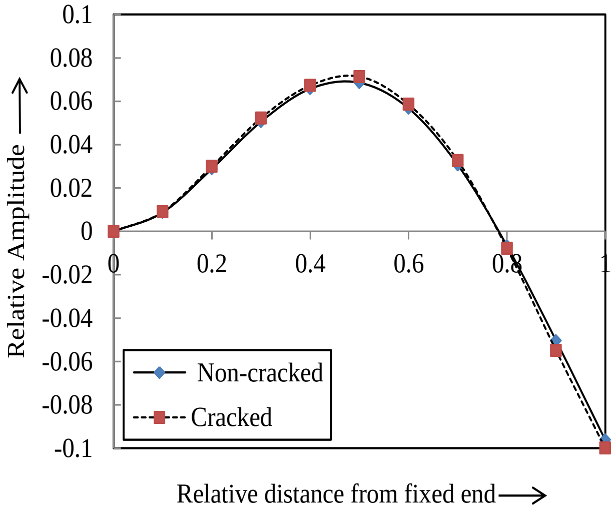

Fig. 3b. Relative Amplitude vs. Relative distance from fixed end (2nd mode of vibration)

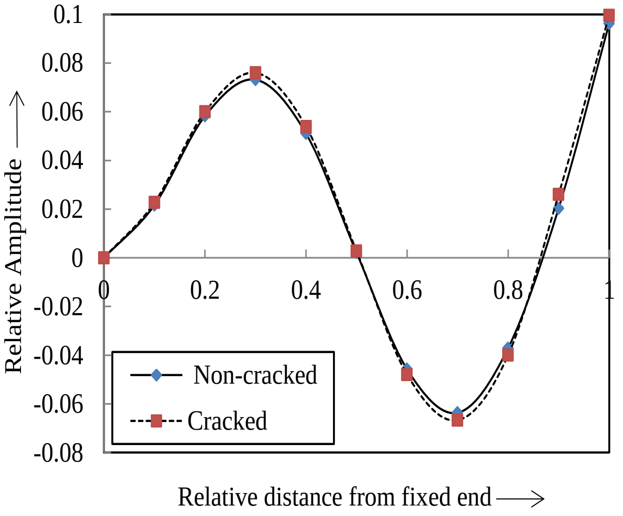

Fig. 3c. Relative Amplitude vs. Relative distance from fixed end (3rd mode of vibration)

III. HYBRID FUZZY-NEURAL ANALYSIS

The dynamic behavior of the beam changes due to presence of a crack, the first three relative natural frequencies and first three average relative mode shape differences of the cracked and non-cracked beam for different crack locations and depths are calculated by FEA and experimental analysis. The measured vibration parameters are used as inputs to the fuzzy segment of the hybrid model and initial relative crack depths and initial crack locations are the output parameters. The first three relative natural frequencies, first three average relative mode shape difference and the output from the fuzzy model are used as inputs to the KSOMsegment of the hybrid model and final crack depths and locations are the output parameters. The measured vibration signatures are used to formulate a series of fuzzy rules and training patterns for the fuzzy and neural model. Finally, the validation of the proposed method is carried by means of experimental results from the developed experimental setup. The fuzzy segment of the hybrid model for cracks prediction has been developed using triangular membership functions. The term used for the inputs are as follows; Relative first natural frequency = “rfnf”; Relative second natural frequency = “rsnf”; Relative third natural frequency = “rtnf”; Relative first mode shape difference = “rfmd”; Relative second mode shape difference = “rsmd”; Relative third mode shape difference = “rtmd. The term used for the final outputs are as follows; Relative first crack location = “rfcl” Relative second crack location = “rscl” Relative first crack depth = “rfcd” Relative second crack depth = “rscd”. The training of the Kohonen’s self-organizing maps is performed by using a specific algorithm. The algorithm responsible for formation of self-organizing maps proceeds first by synaptic weight in network. The complete process or mechanism can be categorized into four parts, i.e. Initialization; Competition Mechanism; Co-operative Mechanism and Adaptive Mechanism.Triangular fuzzy-KSOM hybrid model for identification of cracks is shown in fig. 4.

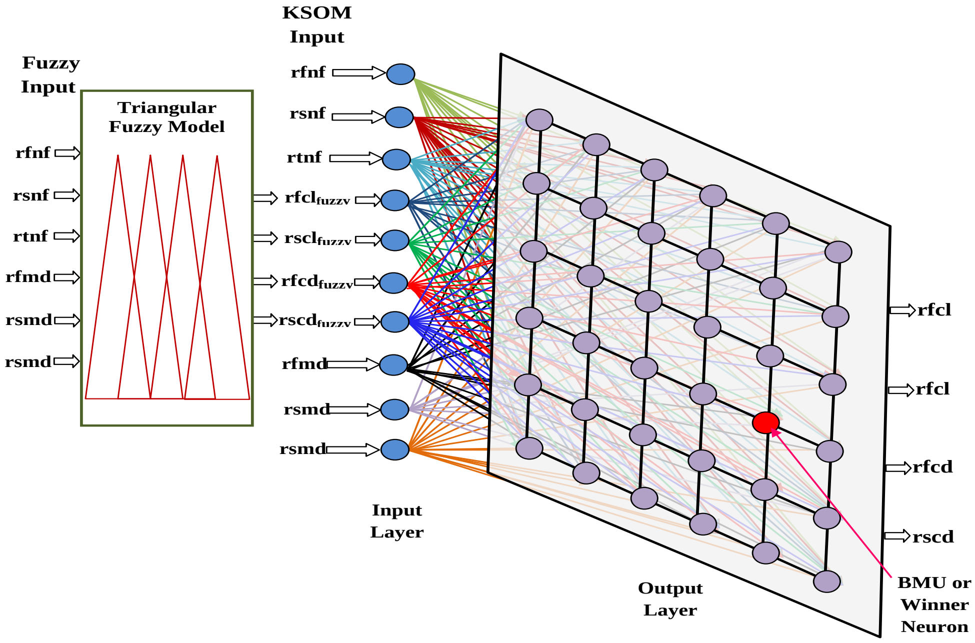

Fig. 4 Triangular fuzzy-KSOM hybrid model for identification of cracks

IV. EXPERIMENTAL INVESTIGATION

To authenticate the finite element analysis result, an experiment has been performed on composite beam. A composite beam was clamped on a vibrating table. During the experiment the cracked and non-damaged beams have been vibrated by using an exciter and a function generator. The vibration characteristics such as natural frequencies and mode shape of the beams have been recorded by placing the accelerometer along the length of the beams and displayed on the vibration indicator. The experimental results are in close justification with hybrid model results. These results for first three modes are shown in fig6. Corresponding finite element results for the cracked and non-cracked beam is also presented in the same graph for comparison purpose. The comparison of results between Hybrid controller, FEA and experimental analysis shown in table 2.

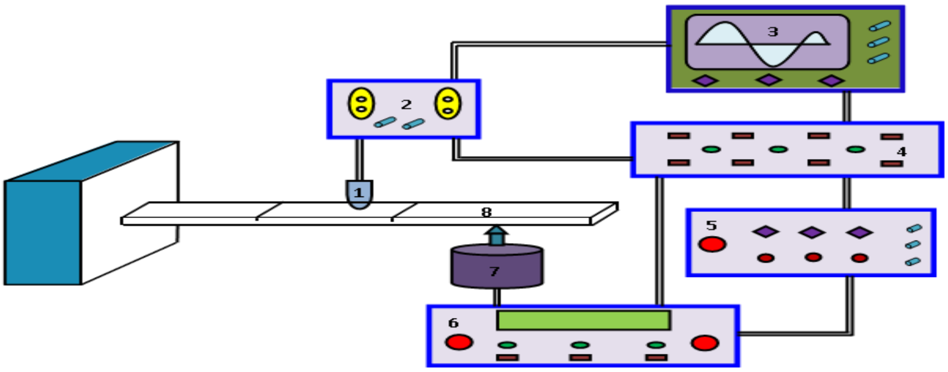

Fig. 5 Schematic Diagram of Experimental Setup

1. Data acquisition (Accelerometer); 2. Vibration analyser; 3. Vibration indicator embedded with software (Pulse Labshop); 4. Power Distribution; 5. Function generator; 6. Power amplifier; 7. Vibration exciter;
8. Cracked Cantilever Composite beam

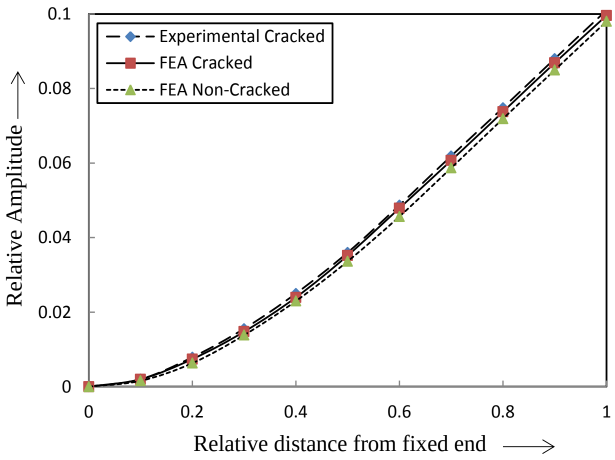

Fig.6a. Relative Amplitude vs. Relative distance from fixed end (1^{st} mode of vibration)

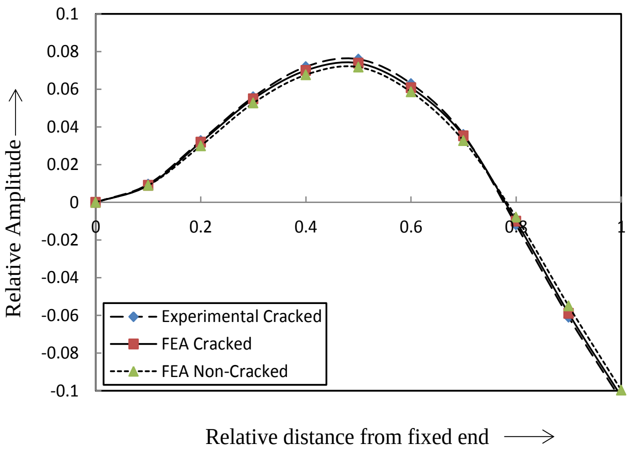

Fig.6b. Relative Amplitude vs. Relative distance from fixed end (2^{nd} mode of vibration)

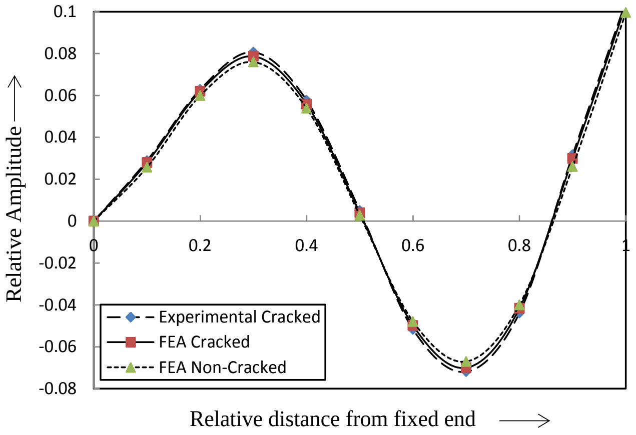

Fig.6c. Relative Amplitude vs. Relative distance from fixed end (3^{rd} mode of vibration)

V. CONCLUSIONS

The following conclusions are drawn from the analyses of above discussed methods:-

1. In the study of vibration reponses of the composite beam shows a variation in mode shapes and natural frequencies at the cracked and non-cracked position.
2. The results derived from finite elementandhybridmethod are compared with the experimental results. They are in good agreement.
3. The total percentage of error in the results of hybrid fuzzy-KSOM model and FEA are 5.9 and 3.10 respectively in comparison with experimental results.
4. This method can be employed as a condition monitoring tool for vibrating damaged dynamic structures.

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Table 2 Comparison of results between Hybrib model, Finite element analysis and Experiment analysis.

Relative 1^{st} natural frequency "rfnf"	**Relative 2^{nd} natural frequency "rsnf"**	**Relative 3^{rd} natural frequency "rtnf"**	**Relative 1^{st} mode shape difference "rfmd"**	**Relative 2^{nd} mode shape difference "rsmd"**	**Relative 3^{rd} mode shape difference "rtmd"**	KSOM controller relative 1^{st} crack location "rfcl" 1^{st} crack depth "rfcd" 2^{nd} crack location "rscl" 2^{nd} crack depth "rscd"				FEA relative 1^{st} crack location "rfcl" 1^{st} crack depth "rfcd" 2^{nd} crack location "rscl" 2^{nd} crack depth "rscd"				Experimental relative 1^{st} crack location "rfcl" 1^{st} crack depth "rfcd" 2^{nd} crack location "rscl" 2^{nd} crack depth "rscd"			
						rfcl	rfcd	rscl	rscd	rfcl	rfcd	rscl	rscd	rfcl	rfcd	rscl	rscd
0.99607	0.99700	0.99829	0.00013	0.00203	0.00240	0.178	0.159	0.416	0.238	0.182	0.162	0.424	0.242	0.1875	0.1667	0.4375	0.250
0.98098	0.99557	0.99892	0.00275	0.00456	0.01064	0.119	0.396	0.832	0.317	0.121	0.404	0.848	0.323	0.125	0.4167	0.8750	0.333
0.99651	0.99425	0.99796	0.00079	0.00264	0.00101	0.297	0.159	0.476	0.238	0.303	0.162	0.485	0.242	0.3125	0.1667	0.5000	0.250
0.99001	0.99318	0.98710	0.00145	0.00571	0.00508	0.238	0.396	0.535	0.159	0.242	0.404	0.545	0.162	0.250	0.4167	0.5625	0.1667
0.98809	0.98584	0.98255	0.00288	0.01210	0.01352	0.357	0.476	0.713	0.238	0.363	0.485	0.727	0.242	0.375	0.5000	0.750	0.250
0.99672	0.98724	0.99719	0.00176	0.00332	0.00594	0.416	0.238	0.535	0.317	0.424	0.242	0.545	0.323	0.4375	0.2500	0.5625	0.333
0.99788	0.97843	0.97519	0.00284	0.01222	0.02349	0.535	0.317	0.654	0.476	0.545	0.323	0.666	0.485	0.5625	0.333	0.6875	0.500
0.99874	0.99877	0.99628	0.00026	0.00475	0.01519	0.594	0.079	0.832	0.396	0.606	0.081	0.848	0.404	0.625	0.0833	0.875	0.4167
0.99114	0.99799	0.99803	0.00010	0.00166	0.00183	0.178	0.238	0.297	0.238	0.182	0.242	0.303	0.242	0.1875	0.250	0.3125	0.250
0.99701	0.98999	0.99803	0.00153	0.00464	0.00239	0.416	0.317	0.535	0.159	0.424	0.323	0.545	0.162	0.4375	0.333	0.5625	0.1667