A CFD research considering the geometry change due to cavitation erosion

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Abstract. It is well known that severe cavitation can cause erosion on the surfaces of fluid machineries. The long time growth of cavitation erosion makes significant mass loss and resultant geometry change of the fluid machineries. This geometry change might cause the change of the flow characteristics of the fluid machineries. The prediction of the change of the flow characteristics due to cavitation erosion are important issue for maintenance of the fluid system. In this paper cavitation erosion on the soft metal specimen is generated in a Venturi tube type apparatus. The erosion geometry is measured by an optical measurement device. The flow inside the apparatus is computed by using Computational Fluid Dynamics considering the measured cavitation erosion geometry. The flow characteristics with and without cavitation erosion are compared.

1. Introduction

In recent years, the prediction methods of cavitation erosion were studied by many researchers [(1-6)]. When the correlation between some cavitation aggressiveness based on cavitation CFD results and erosion rate in the experiments is established, the erosion rate on any part of the fluid machineries can be predicted numerically. However more detailed researches would be required from the standpoints of fluid dynamics, material science, computational fluid dynamics and computational structure analyses for practically useful prediction methodology. On the other hands, sometimes fluid manufacturers have to make a diagnosis about the health conditions of their products those have already been eroded by cavitation on site. Traditionally visual judgments have been carried out based on the observable depth and area of the erosion. If the three dimensional geometry data can be input to numerical analysis software, hydraulic performance and structural strength can be evaluated quantitatively considering cavitation erosion. In the previous study, approximated geometry of cavitation erosion was proposed for the input data of numerical analyses[(7)]. Recently three dimensional geometry profiling devices are available in industries with reasonable costs. Most of them are non-contact type and obtain geometry data optically. Many types of principles such as triangulation, time of flight measurement, phase shift analysis and so on, are utilized for these devices. By these devices, any types of surface damages such as abrasion, crack, fracture, corrosion and so on can be measured. In this research the soft metal specimen is exposed to cavitation in the venturi tube type apparatus. The generated cavitation erosion geometry is profiled by confocal laser scanning microscope. Cavitation CFD is carried out for the flow passage with cavitation erosion geometry. This research could be the preliminary study for the development of health evaluation system of the fluid machineries.

2. Experimental Results

The venturi tube apparatus in this study is seen in Fig.1. It is a hybrid of conventional convergent divergent venturi and Shal'nev type venturi with a cylindrical pin[8,9]. The cavitation tunnel apparatus by Pallabazzer and Mancuso is used as a reference of the convergent divergent geometry in this study[10]. It has rectangular cross section.

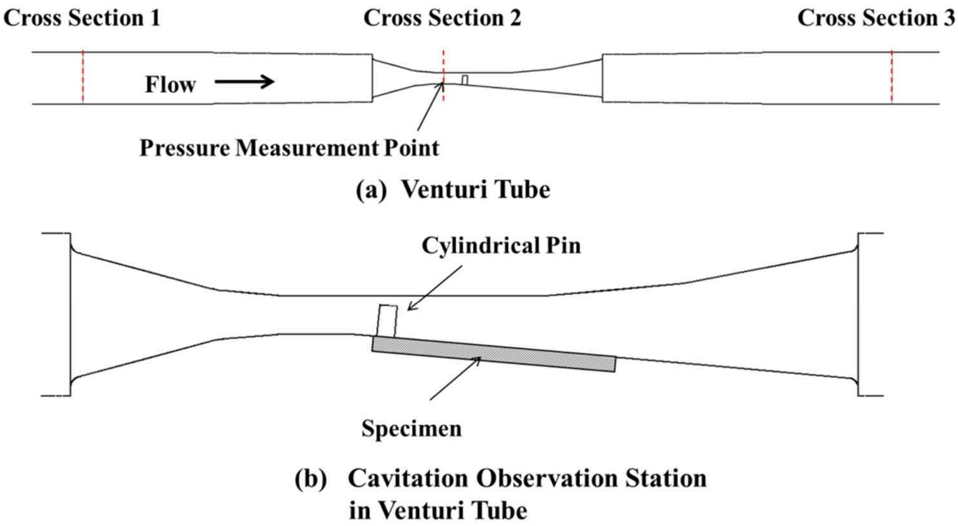


Fig.1 Experimental Apparatus of the Venturi Tube

Length scale of the throat at the cross section 2 is in the order of centimeter. Degassed water of room temperature is used and the velocity at the throat is in greater than 10 m/s. At first simple convergent divergent geometry was adopted, however generated erosion by cavitation is very weak. By addition of a cylindrical pin, the erosion rate is significantly increased. In the experiments, cavitation coefficient σ at the cross section 2 is kept constant to 2.6. In Fig.2 instantaneous photograph of cavitation is seen. Cavitation bubbles exist inside the Karman vortices at the downstream of the pin and twin eroded areas are increased on the specimen.

Fig.2 Cavitation at the downstream of the pin

Fig.3 Cavitation Erosion after 100 hour Exposure

Seven specimens of soft metal with polished surface are prepared. They are exposed to cavitation for 2, 5, 10, 15, 20, 50 and 100 hours respectively. The cavitation erosion after 100 hour exposure is seen in Fig.3. The erosion geometries are profiled by confocal laser scanning microscope (Keyence VR-3000). The cross section of the erosion geometries for the cases of 2, 10, 50, 100 hour exposure are seen in Fig.4. Length and depth of the erosion is normalized by pin diameter.

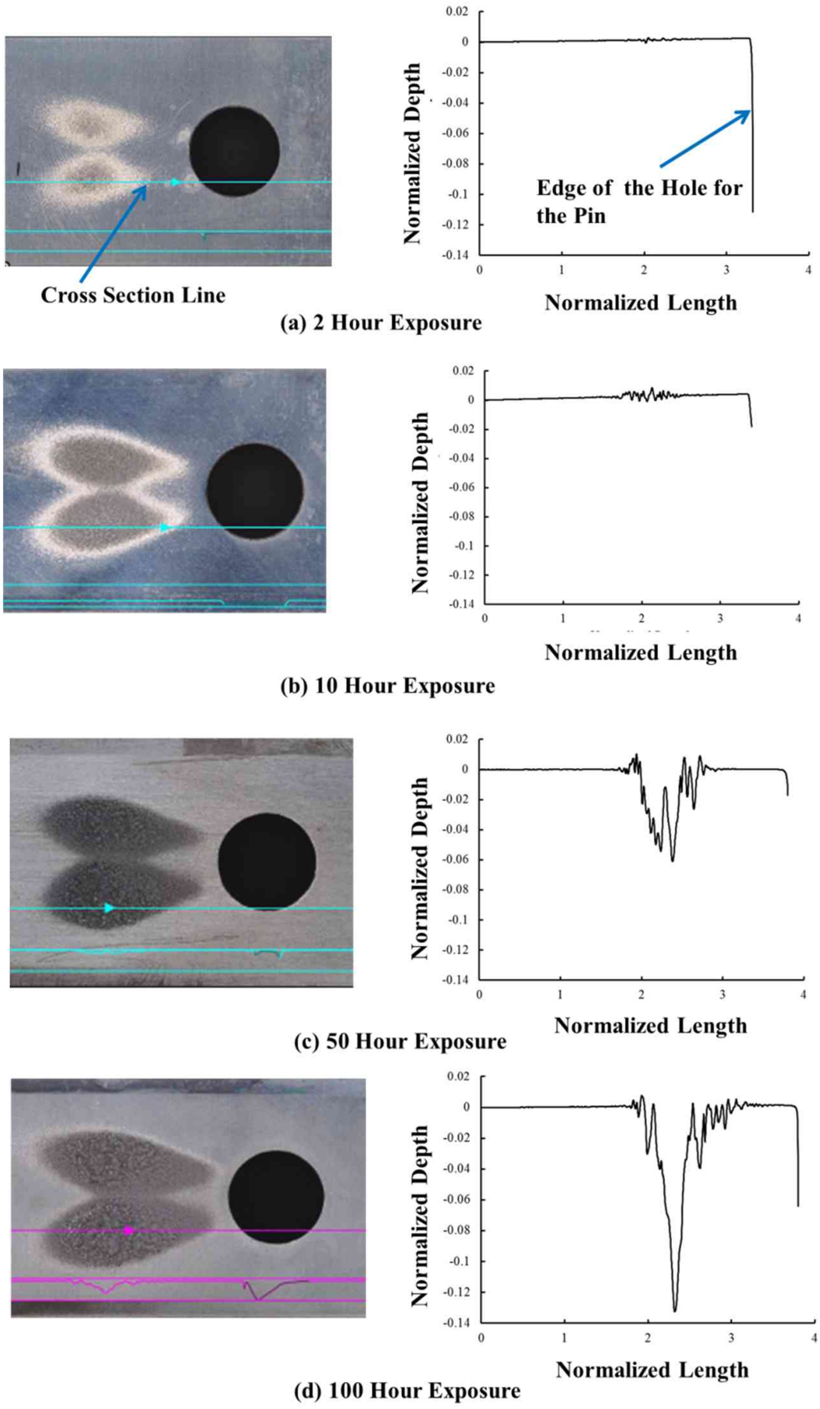
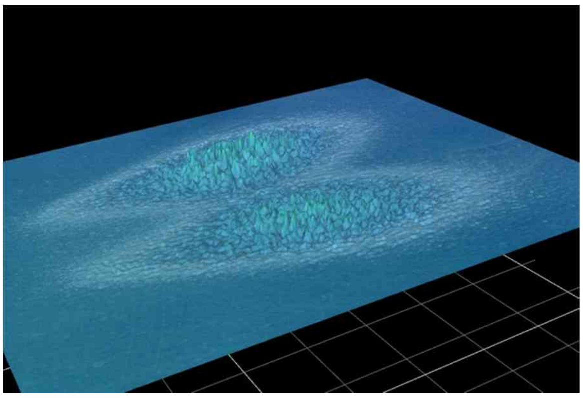
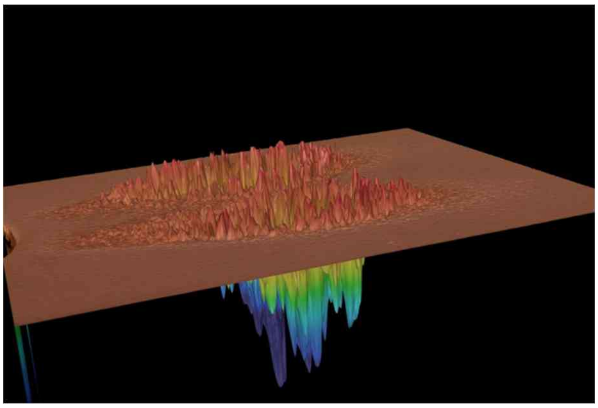


Fig.4 Cross Section of the Erosion Geometries

As seen in Fig.4 the cross section line of the specimen of 10 hour exposure shows not an erosion concave but the convex with many peaks. In the initial stage of the cavitation exposure so called incubation period, soft metal is not eroded but deformed plastically. In these experiments the incubation period looks continued for about 15 hours, then the erosion with mass loss looks starting. The specimens of 50 and 100 hour exposure show clear erosion concaves.



(a) The Specimen of 10 Hour Exposure



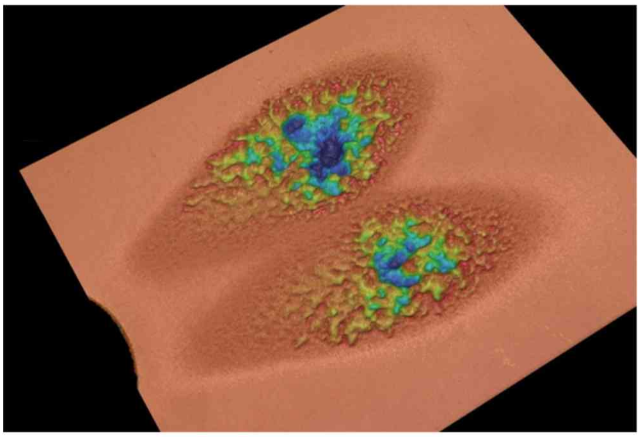
(b) The Specimen of 100 Hour Exposure

Fig.5 Three Dimensional Images of the Erosion

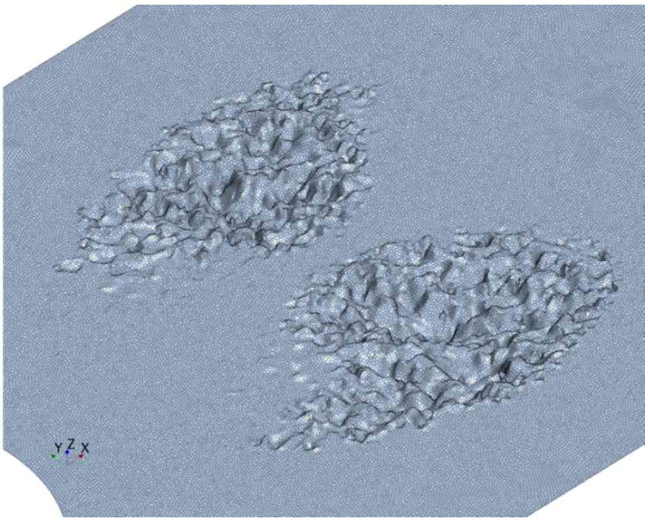
Three dimensional images of the specimens of 10 hour and 100 hour exposure are seen in Fig.5 respectively. Peak height and erosion depth are highly magnified in Fig.5. In the case of 100 hour exposure the erosion hole is surrounded by many peaks those are created in the plastic deformation. The geometry of the erosion in the specimen of 100 hour exposure is used as the boundary of the cavitation CFD as written in the following section.

3. Computaion Results

The geometry data of cavitation erosion obtained by optical profiling are digitized and are input to grid generator software for CFD. Polyhedral meshing is used for portraying the complicated geometry



(a) Original Profiled Erosion with Height Contour

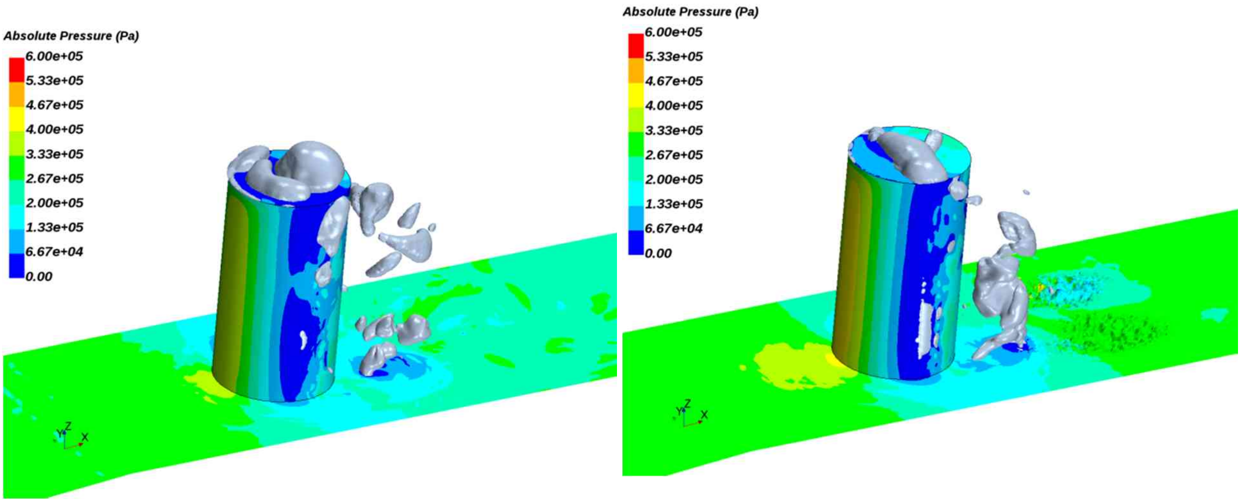


(b) Gridded Erosion Geometry

Fig.6 Numerical Grids of the Erosion

of the erosion. Generated numerical grids are seen in Fig.6. Due to the limitation of the CPU resources for this research, whole digital data those are obtained by optical profiling cannot be used for the gridded geometry. Fine erosion structures are decimated and relatively large up and down waves of the eroded surface remain in the grid generation. This issue could be much important in the case of computation considering the erosion geometry on much larger machineries such as marine propellers of the large ships, large pump impellers and hydraulic turbine runners and so on. Because the scale ratio of fine erosion structure to the huge machineries must be extremely high. The combination strategies of moderately accurate portrayal of the erosion geometry by numerical grids and some loss function for sub grid scale surface roughness model on the eroded area should be established. This could be the future subjects.

For the evaluation of the effects of the erosion on hydraulic characteristics, the flow inside the venturi tube without erosion is also computed. Grid numbers of the cases with/without erosion are 29,184,238 and 29,247,558 respectively. Commercial CFD code Star-CCM+ is used for computation. Volume flow rate is specified at the inlet of the computation domain. Static pressure is specified at the outlet. Turbulence model is SST k–ω. Wall function named All y+ Wall Treatment in Star-CCM+ is used. At first steady incompressible computation without cavitation is carried out. The mass averaged total pressure difference between cross section 1 and 3 is 77 kPa in the case without erosion and is 92 kPa in the case with erosion. This difference means the addition of the hydraulic loss of the flow due to the geometry change by erosion. After the incompressible computation, steady cavitation CFD starts by decreasing the static pressure at the outlet slightly. Homogeneous mixture cavitation model based on Rayleigh-Plesset equation in Star-CCM+ is used. After adjusting the cavitation coefficient at the pressure measurement point to the same value of 2.6 to the experiments in steady computation, unsteady cavitation calculation starts. For observing the complicated vortex structure with cavitation, Large Eddy Simulation is adopted. Stable unsteady cavitation computation by LES is well accomplished in this study. Typical instantaneous computation results are seen in Fig.7.



(a) Computation without Erosion (b)Computation with Erosion

Fig.7 Cavitation CFD Results of Static Pressure Contour and Iso-surface of Void Fraction of 1%

An example of the final phase of bubble collapse on the wall of specimen in the case without erosion is shown in Fig.8. Shed cavitation bubbles from the pin are flown downstream and collapse

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and disappear. The location of the bubble collapse shows good correlation with the location of the erosion in the experiment.

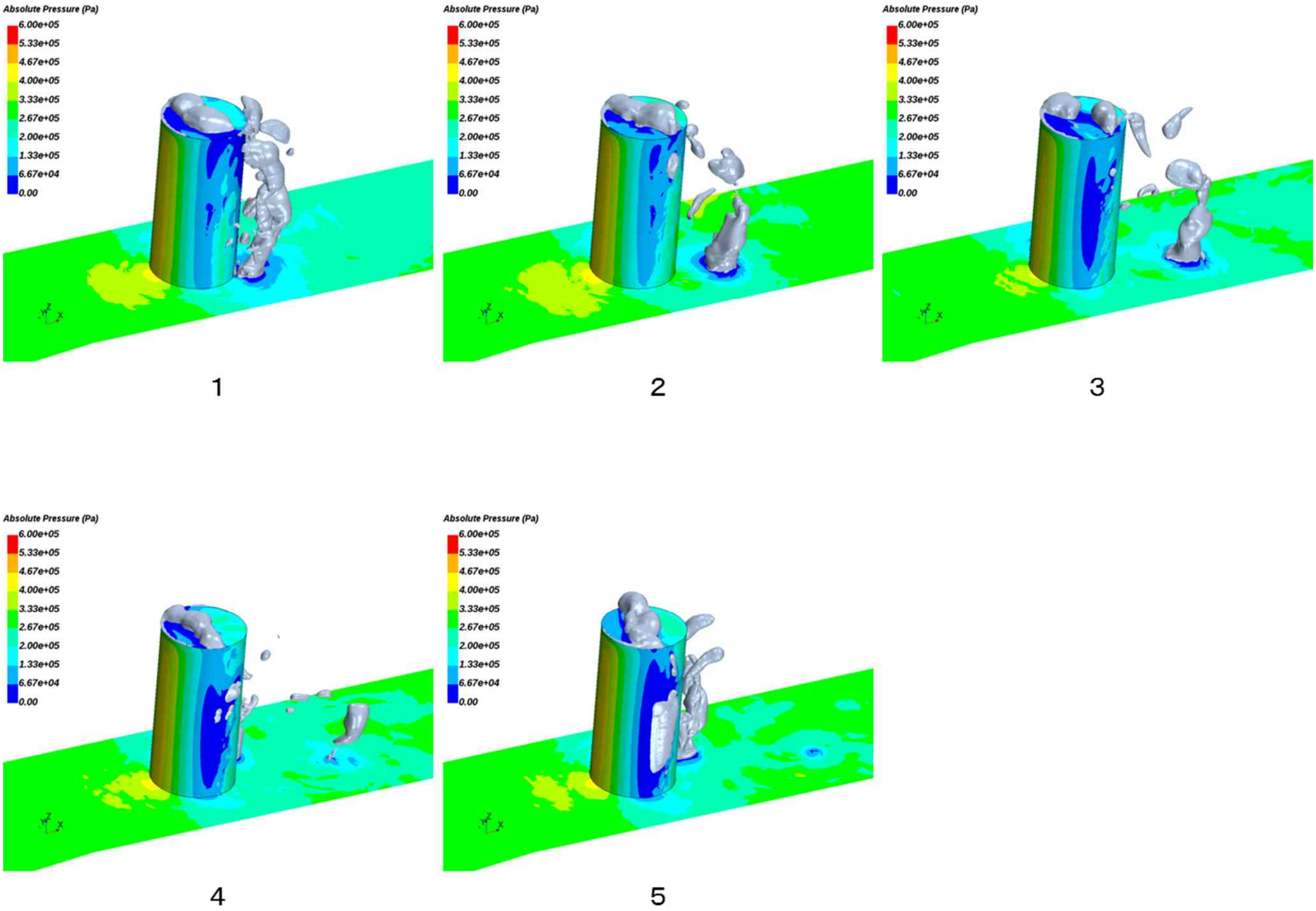
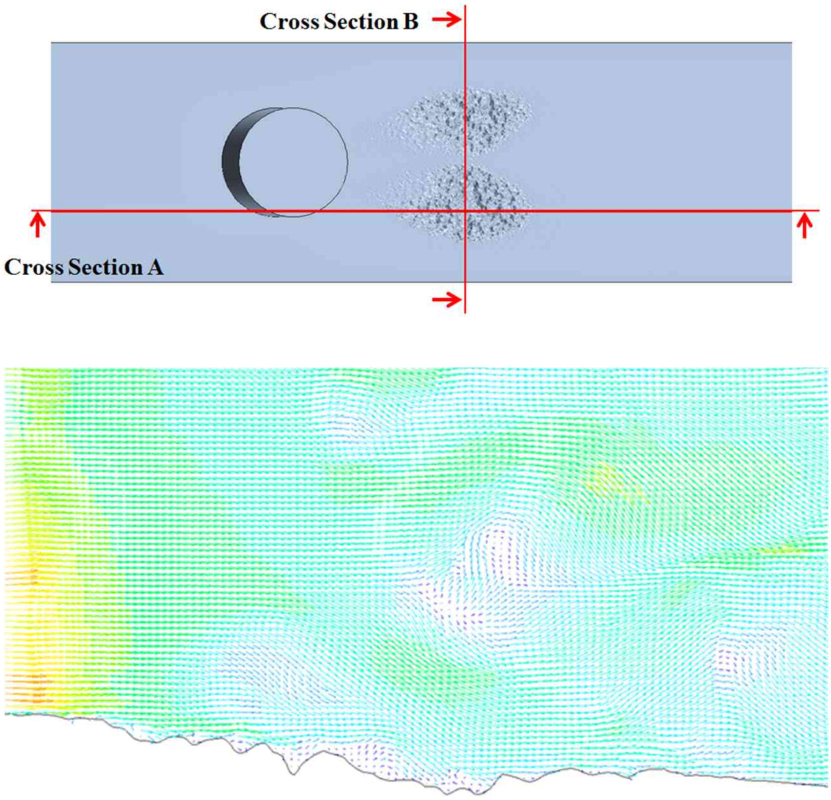


Fig.8 The Sequence of Bubble Collapse Observed in CFD Results with Static Pressure Contour and Iso-surface of Void Fraction of 1% (Time Interval 0.4ms)

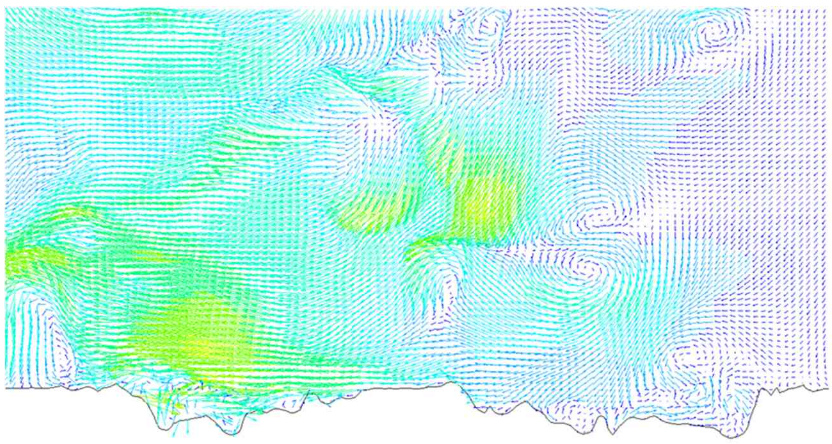
The flow around the erosion is very complicated. The instantaneous velocity vectors around the erosion are seen in Fig.9. Many vortices are observed in the main stream and the separation is clearly seen in the erosion concave. From a view to the cross section B, the flows around the twin erosion concaves are significantly asymmetric perhaps due to the nature of Karman vortices and also asymmetry of the erosion geometry itself. More detailed examinations and comparisons of the flow characteristics are going on.

Conclusions

Cavitation erosion generated on the soft metal specimens in the venturi tube apparatus are optically profiled by confocal laser scanning microscope. The obtained geometry data is input to grid generator software and numerical grids portraying the erosion geometry can be generated. Stable cavitation CFD by LES can be carried out. Very complicated flows are observed in the numerical results. This research could be the preliminary study for the development of health evaluation system of the fluid machineries considering cavitation erosion.



(a) The Results of Cross Section A



(b) The Results of Cross Section B

Fig.9 Instantaneous Velocity Vectors around the Erosion

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