ABSTRACT

BI-MODAL FORCING OF A SHARP-EDGED IMPINGING JET WITH
CONSIDERATION OF WALL COOLING

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With the current oil price inflation, there is a crucial need for reducing the fuel consumption of gas turbines/jet engines by increasing the turbine efficiency. More crucially, this would also reduce carbon emissions due to less fuel consumption, which is necessary to combat global warming. Enhancing the gas turbine efficiency can be fulfilled by increasing the turbine’s operating temperature via enhanced cooling of the turbine blades. One of the methods typically used for effective cooling of gas turbine blades utilizes impinging jets. The present work is primarily focused on investigating the change in the development of the vortex structure of an impinging jet caused by a novel flow excitation technique. A secondary objective is to examine if this change might have the potential for enhanced cooling of the impingement surface. The flow excitation approach, known as bi-modal forcing, utilizes two excitation frequencies: the initial instability frequency of the jet shear layer and its subharmonic. This type of forcing involves
several parameters: the intermodal phase ($\phi$), the modal amplitude ratio ($AR$), and the overall forcing level. While an abundance of studies exists on pure harmonic excitation of impinging jets, there is a lack of similar investigations utilizing bi-modal forcing. With rare exceptions, existing studies of bi-modal forcing are for the non-impinging jet.

The present study utilizes an impinging jet with a sharp-edged exit of diameter $D$ at a Reynolds number based on the jet exit velocity and diameter of $Re_D = 4,233$. A high-speed time-resolved flow visualization study is conducted at a forcing amplitude of 0.3%, $AR = 1$, the full range of $\phi$ ($0° - 180°$), and jet to impingement plate distance of $H/D = 2$. The flow visualization results are complemented with single hot-wire measurements for cases deemed interesting. Flow visualization experiments are also conducted for $AR = 0.5$ and $2$, forcing level of 0.1% and $H/D = 3$ and $4$. Temperature sensitive paint is used for preliminary measurements of Nusselt number on the impingement plate under constant heat flux heating. The natural jet and pure-harmonic forcing at the fundamental and the subharmonic frequency are also studied as benchmark cases for bi-modal forcing.

Results show that all modes of forcing accelerate the development of the vortex structure by producing two vortex pairings ahead of the impingement plate at $H/D = 2$. This double-paired structure is rarely seen in the natural jet and is promoted the most under pure subharmonic forcing and bi-modal forcing. The intermodal phase is found to have a strong effect with the double-paired structure remaining symmetric (between the visualized top and bottom parts of the shear layer) at $\phi \approx 165°$, or exhibiting significant asymmetry and disorganization at $\phi \approx 90°$. The main distinction between bi-modal forcing at $\phi = 165°$ and pure subharmonic forcing is that the double-paired vortex structure is more persistent and occurs with better cycle-to-cycle repeatability in the former case. With subharmonic forcing alone, the vortex structure is more energetic but exhibits
some random switching between the symmetric double-paired structure, asymmetric structure, and single-paired structure. Overall, the promotion of double-pairing leads to faster narrowing of the jet core and stronger vortex-wall interaction. Preliminary heat transfer measurements also indicate a positive influence of bi-modal forcing on heat transfer in the stagnation zone accompanied by negative influence at larger radial locations. These opposing effects can be balanced by the choice of $\phi$. The heat transfer data are preliminary and need to be confirmed and examined in further depth by future studies.

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