Chapter-2

Literature Review

2.1 A Brief Technical Review of Shape Memory Alloy (Smart Material)

This chapter reviews the previous work done related to the shape memory alloy. The literature survey carried out served two purposes. Firstly, it was meant for obtaining a complete picture of various material combinations for shape memory alloy and their performance, experimental analysis, numerical analysis, vibration control for various applications and optimizations. Secondly, it was for obtaining the information about the comparative study of NiTi SMA spring used in structural vibration control. Literature review related to present work shows the research proceeded along following directions.

2.1.1 A Brief Review on Modeling and Analysis by Experimental and Analytical Method.

Vinicius Piccirillo et al. [23] have analyzed numerical response of single degree of freedom dynamic system attached with SMA spring for damping and vibration isolation. The experimentation was performed on DC motor-structure system. As torque generation capacity of DC motor was limited. Hence temperature was considered as one of the important criteria responsible for dynamic behaviour of system during phase change. The graphs were plotted for displacement vs. velocity and frequency vs. magnitude. The author concluded that it is possible to get regular, chaotic, hyperchaotic motion depending on voltage of DC Motor. The chaotic and hyperchaotic orbits were characterized and Sommerfeld effect was observed at resonance and jump phenomenon.

Z. Lekston et al. [28] have presented phase transformation of TiNiCo and NiTi shape memory alloys by temperature X-ray diffraction. The suitable heat treatment was suggested to determine reversible B2→R transitions and shape memory effect in small temperature range. The effect of cobalt in shape memory alloy was verified in
cooling and heating transitions. Experimentations proved that, it is feasible to observe transformation courses and calculate characteristic temperatures of transformation during heating and cooling of shape memory alloy. The author concludes that alloy with shape recovery in small temperature range below human body temperature can be used for medical implants, devices under the influence of human body and technical applications.

C. Lexcellent et al. [29] have presented improvement in thermo-mechanical model of non-isothermal behaviour of SMA by taking into consideration response of trained material. The training procedure of Cu-Al-Ni shape memory alloy was discussed related with two way Shape Memory effect (TWSME). Experimental result shows that stress is an important parameter in training process. The training procedure of Cu-Zn-Al shape memory alloy was also discussed with resulting TWSME. The global set of parameters was identified. The simulation of TWSME cycle for several values of training stresses was obtained. The numerical results were validated with experimental one. The author concluded that combination of his work with Raniecki was useful for design of structures made from SMA. However, modelling of such complex phenomenon requires huge set of parameters.

Keitaro Yamashita et al. [37] have presented the shape recovery force of TiNi fibre reinforced composite by electric heating. The paper deals with reinforced composite material, which is embedded polymer matrix and material is laminated with SMA. The specimens were made according to SMA characteristics. The effect of temperature on strain for three specimens A, B & C was noted on graph. The experimental approach was consisting of single axis tensile test machine having thermostatic bath in the centre. The specimens were electrically heated for tensile load of 6 Mpa. Based on experimental results, graph of displacement vs. heating time and temperature vs. heating time were plotted for all three specimens. Finally, the author concludes that type A & B SMA are best composite material and can be made by using electric heating. The shape recovery is maximum for maximum number of SMA fibres.

T. Kniknie et al. [39] have presented the use of shape memory alloy thin films to tune dynamic response of micro cantilevers. The SMA coating was used to modify the dynamic response of AFM cantilever. The cantilever specimen made up of silicon was coated with NiTi film. The dimensions of cantilever were length 250µm, width
35 µm and thickness 2µm. The thickness of coating was 1µm. The experimental setup was consisting of cantilever beam, sensor, heating element, optical measurement head and laser detector grating unit (LDGU). The effect of temperature and current used for experimentation was found on stresses. The frequency response of NiTi coated beam for length 250µm and 350µm was plotted against amplitude for increasing value of current. Finally they had concluded that SMA thin film can modify dynamic behaviour of micro cantilever. First peak was attributed to flexural mode. The second peak was not obtained by calculation of higher order flexible response frequencies. The author has observed the separation of two peaks during phase transformation.

Marcelo A. Savi et al. [40] have presented numerical investigation of adaptive vibration absorber using SMA. The SMA with adaptive tune vibration absorber (ATVA) was developed for nonlinear response of a system subjected to external excitation. One degree of freedom oscillator with SMA was analyzed for dynamic response. It was assumed that, SMA phase transformation does not take place for small amplitude of vibration. The results of SMA-ATVA are compared with TVA. The mathematical modeling for single degree of freedom SMA oscillator was done by numerical simulation. The influence of temperature was found on vibration reduction. The thermo mechanical behaviour of SMA was described with the help of model. Finally, the comparison of SMA-ATVA and TVA was done. From comparison, it was concluded that, SMA-ATVA eliminates the resonance frequencies obtained in TVA. Also it has ability to actuate at particular frequency controlled by alternating temperature.

G.M. Loughran et al. [42] have discovered the fracture of SMA CuAlNi single crystal. The specimens were cut from single crystal. They were notched and loaded in tension. Eight specimen orientations were selected for experimentation. The specimens were prepared for geometries of single edge notch, modified single edge notch and compact tension notch. These specimens were studied experimentally. Each of these specimens were heat treated to temperature of 900°C for 1 hr followed by ice water quenching. Uniaxial tensile test was carried out on all specimens using Instron 4502 load frame. Total 16 specimens were designed for fracture studies. Two specimens have orientation I, five specimens have orientation II, four specimens have orientation III and one specimen with orientation IV, V, VI, VII & VIII. These entire specimens were grouped in two groups. From this experimentation, it was concluded
that fracture behaviour of material was related to structural transformation and fracture direction.

M. Izadinia et al. [44] have studied the structure and properties of non structured SMA produced by melt spinning. The Cu-13.2Al-5.1Ni SMA material was used for experimentation. The specimen was of dimension 60x30x0.9 mm prepared by cast ingot followed by solution treatment at 950°C for 1hr and water quenching. The experimentation of rapid solidification technique (rapid cooling) was carried on specimen. The nano structure ribbons were characterized using Philips-XL 30 scanning electron microscope with dispersive x-ray analyzer. The phase transformation regarding coarse grain and nano sample was determined by differential scanning calorimeter (DSC) technique. For comparison, the specimen was bent to 90°. The microstructure and Shape Memory Effect (SME) were observed. From experimentation, author concluded that, nano structured Cu-13.2Al-5.1Ni have better SMA properties than initial coarse grain structure.

Yongsheng Ren, et al. [47] presented a modeling and dynamic behaviour of rotating composite shafts with SMA wires. The rotating shaft is modeled with thin walled composite of circular cross section, with SMA wires embedded along the length of shaft. The effect of increase in stiffness and tension in wire, due to phase recovery stresses was studied. Theoretically, the equations of motion were found out by using base of variational-asymptotical method (VAM) theory for obtaining correct modeling effect of transverse shear stress as added in VAM theory. These equations of motion are solved by using Galerkin procedure. The recovery stress of constrained SMA wire was found out by using Brisbon theory. From this model, they have obtained the relation between first three natural frequencies and rotating speed of shaft with and without SMA wire. The author also determined the relation between first three natural frequencies and temperature for shaft with different SMA wire fraction. It was concluded that SMA phase transformation reduces the whirling speed and increases critical speed of shaft, with increase in SMA wire fraction.

Samuell A. Holanda et al. [48] had studied the complex stiffness of vibratory mechanical system with SMA coil spring actuator. In this paper, the stiffness and damping capacity of SMA helical coil spring was studied by attaching it to a system of one degree of freedom. The system is subjected to unbalanced force with temperature control. The modeling was done for unbalance rotating system and
complex stiffness. Thermomechanical properties were considered for experimentation. The response of system with SMA spring in martensite phase (25°C) and austenitic phase (70°C) was determined by harmonic excitation. The analysis of dynamic behaviour of NiTi wires was performed and graph of temperature vs. elastic modulus was plotted. Damping factor of system was also measured experimentally. Based on this work, author had concluded that elastic modulus of NiTi SMA wire for austenitic phase is maximum as compared to martensitic phase. Damping capacity of NiTi SMA wire decreases with increase in excitation frequency. Damping factor of system is maximum at martensitic region and minimum at austenitic region.

Y.M. Parulekar, et al [49] have presented a non-linear model of pseudoelastic SMA damper, considering residual martensitic strain effect. Thermomechanical model of superelastic SMA damper having multi-linear stress-strain relationship was used in the study. The model possesses cyclic effect of shape memory alloy. The model was attached to a steel frame having one degree of freedom, was analyzed experimentally. The force deformation characteristics of thermomechanical model with cyclic effects were compared with simplified model and thermomechanical model. The reduction in the response of structure with SMA damper for increase in base excitation was discussed. The author concludes that proposed thermomechanical model with cyclic effect is more effective in capturing real characteristics of SMA than other models discussed in paper.

Zhi-wen zhu, et al [50] had presented non-linear dynamic characteristics and optimal control of SMA composite wing, subjected to stochastic excitation. In this paper analysis of non-linear dynamic characteristic of cantilever SMA composite beam subjected to stochastic excitation was done. The dimensions of specimen were of length 12 cm, width 0.35 cm and thickness 0.4 mm. Partial least square regression software SIMCA-P was used to find variable importance (VIP) and coefficient value of each parameter. This software automatically predicts the stress-strain behaviour with input as coefficient value of each parameter. For modeling SMA composite wing, SMA thin plate was pasted in inner surface of wing. Dynamic characteristics of SMA composite wing subjected to in-plane stochastic excitation were studied experimentally. Stochastic air flow was produced by using random guide vanes in low
speed wind tunnel. The author concludes that optimal control strategy proposed in this paper is helpful for SMA applications.

Ali Abolmaalia et al. [20] have studied viability of steel with shape memory alloy (SMA) in two phases. In Phase-I, the shape memory alloy super-elastic effect was determined by giving optimum heat treatment to SMA fasteners at 300°C and 350°C for maximum energy dissipation. Monotonic tensile testing was conducted to determine the transformation stresses, ultimate stresses and failure strains. Cyclic testing was conducted to determine strain accumulation and residual strains after each cycle. Tensile testing was conducted to determine fracture strains and ultimate stress. The stress vs. strain curves were plotted for HT 300 and HT 350. In Phase-II, 4 t-stubs connection test were performed on steel and SMA double-ended threaded rod fasteners. The comparison of energy dissipation of SMA fastener and steel SMA fastener was done. It was concluded that energy dissipation of t-stubs with SMA fastener was more than those with steel for particular stress level.

2.1.2 A Brief Review on Various Material Combinations used in Shape Memory Alloys

Bikas C. Maji et al. [12] have discovered the effect of microstructure on shape recovery of Fe-Mn-Si-Cr-Ni stainless steel Shape Memory Alloy. Three specimens were prepared for experimentation. [A – Quenched at 1000°C for 1 hour, B – Heat treated at 1150°C for 1 hour and water quenched, C – Heat treated at 900°C for 1 hour and water quench.] The variation of shape recoveries with pre-strain at different temperatures 200°C, 400°C and 600°C was found experimentally for each of three specimens. Bending test was carried out for measurement of shape recovery of alloy specimen. These specimens were tested for tensile strength for each of three microstructure condition. It was concluded that maximum shape recovery was obtained when recovery temperature is 600°C with microstructure consisting of austenite matrix with Fe₅Ni₃Si₂ intermetallic phase at grain boundaries and pre-strained was less than 2%. From this technology, It is concluded that microstructure containing austenite & Fe₅Ni₃Si₂ intermetallic phase due to higher fraction of pseudoelastic in pre strain produces better shape memory property. The presence of δ-ferrite in microstructure reduces the shape recovery during pre-straining increases the amount of irreversible processes.
R.A. Shakoor et al. [13] have suggested samarium contents iron based shape memory alloy. He prepared four specimens with and without samarium contents. All specimens were strained by 5% till six training cycles. After completion of each cycle, stress, strength and shape memory effect was observed. It was found that shape memory effect, strength, c/a ratio and tendency of nucleation increases with increase in samarium contents and superior at 0.64%. It was demonstrated that the samarium additions have produced significant influence on the shape memory behaviour of iron based alloys. The strength of specimen decreases if samarium contents increases beyond 0.64 %. The nucleation of α along ε martensite in microstructure was responsible for reduction of strength of specimen with softening.

G D Liu et al. [14] have determined the effect of internal and external stresses and two way shape memory effect on Co_{49}Ni_{21.6}Ga_{29.4} single crystal. It was noticed that tensile force was observed along [0 0 1] direction due to existence of internal stresses. When external compressive force was applied along same direction, the deformation was continuously changed from +1% to -2.3%. Loading compressive stress to [1 1 0] direction, transformation strain value was continuously increased from -2% to -4% depending on pre-stressing. Researcher obtained the optimized direction as [1 0 0] for low strength and stress and [1 1 0] direction for high strain and stress. It was concluded that Shape Memory Effect can be controlled in magnitude and direction by adjusting internal and external stresses.

S. Rajasekhar et al. [19] have developed magnetic shape memory alloy which exhibit lower twinning stresses to respond at lower magnetic field. It was concluded that, if shear stress acting on twin dislocations due to magnetic field, is less than peierls stresses and/or yield stresses of Ni_{2}MnGa, the magnetic shape memory effect will not be observed. Experiments conducted prove that magnetic field of 400 kA/m produces stresses which exceeds peierls and yield stress of Ni_{2}MnGa. Due to this, twin dislocations motion occurs resulting in translation of twin boundaries and re-orientation.

Kneissl et al. [27] have presented two-way shape memory effect (TWSME) in Ni-Ti, NiTiW and CuAlNi by thermo-mechanical heat treatment called training. The experimental result shows that softer material can be trained easily as compared to the samples of higher strength. The annealed sample shows greater shape memory effect than cold worked sample. The binary samples have more TWSME than ternary
samples. It is also noted that TWSME is inversely proportional to strength of the specimen. The factors affecting the development and stability of the intrinsic two-way shape memory effect were discussed. The author conclude that thin ribbon were produced from CuAlNi which exhibits shape memory effects after melt spinning, but low ductility was observed. Adding boron content in alloy was able to produce finer microstructure with more ductile ribbons.

Zhang Wei et al. [33] have improved the shape memory effect in Fe-Mn-Si-Cr-Ni alloy by fabrication. They had produced the fine grained bulk Fe-Mn-Si-Cr-Ni shape memory alloy by equal channel angular pressing (ECAP). They have studied the structure after pressing, annealing and martensite phase transformation in fine grained alloy. Experimentally the alloy was prepared in induction furnace at 1373K for 15H and the ingot was produced by forging to a size of 15 mm. This ingot was annealed for 30 minutes, followed by water quenching. They have noted the effect of annealing temperature on shape recovery of alloy. Also the effect of ECAP on stress induced martensite transformation and annealing temperature on microstructure was studied. From this experimentation, it was concluded that fine grained Fe-Mn-Si-Cr-Ni shape memory alloy can be obtained by ECAP. The shape memory effect was improved to 95% in comparison with 78%, obtained at room temperature by lowering the deformation temperature to 200K.

N. Cimpoesu et al. [35] have presented the effect of stress on damping capacity of CuZnAl shape memory alloy. The alloy was prepared in furnace and its chemical composition was determined through spark spectrometry analysis. The specimen was prepared for the Cu54.9Zn26.5Al6.44 shape memory alloy. The test was performed for above specimen for work frequency at 1Hz and 303K to 573K. The material behaviour under tension was found at forged and laminated state for different heat treatment. From this, they have observed that forged sample is more ductile than laminated, heat treated and water quenched treatment with internal friction. The effect of internal friction, elastic modulus & amortisation modulus vs. temperature was plotted on graph. Author obtained the alloy with good shape memory effect and damping properties. The alloy obtained here can be used in various practical applications, because it gives good internal friction at temperature 363K for deformed and tensioned state.
2.1.3 A Brief Review on Vibration Control using SMA.

Gianluca Diodati et al. [11] have focused on design of fiber glass laminated structural element with SMA wires. The dependence of dynamic behaviour with respect to number of SMA wires and different initial stress conditions were presented. He presented the numerical specimen that was simulated and analyzed through MSC/NASTRAN code. Theoretical & numerical results of natural frequency of specimen were validated. The numerical prediction was done for mode shape and modal frequencies up to 1000Hz. He had shown the effect of frequency variation for single wire and increase in number of SMA wires. With increasing weight of wires, the natural frequencies were shifted significantly. He also found the effect of increase in temperature of SMA wire on frequency. For larger initial stress condition, frequency shift is less. During validation, he found 2.5% of error in numerical and theoretical model for 110N.

Kin-Tak Lau [15] have introduced composite beam with embedded SMA non-prestrained and prestrained Wires. The dynamic response of SMA composite beam was determined theoretically and experimentally for clamped-clamped beam, simply supported beam and clamp free beam. The natural frequency and damping ratio was determined for above mentioned boundary conditions. It was observed that natural frequency was less significant for nonprestrained wires. The damping ratio of SMA composite beam increases with increase in temperature of embedded wires with and without being prestrained. The actuated prestrained wires in clamped-clamped condition produces high tensile stresses in composite beam which results in increase in natural frequency. It was observed that for even small change in natural frequency, the damping properties were significantly improved. The theoretical and experimental results were validated.

Shi-Rong Li et al. [17] have worked on thin circular plate embedded with shape memory alloy wires placed in radial directions and plate is heated uniformly. The natural frequencies for free vibrations of thermally pre-buckled and post-buckled circular thin plates were obtained for simply supported and clamped condition. The radial movement of simply supported plate was restricted. The author noticed that due to increase in weight of the plate and decrease in the deflection due to SMA wires, frequency increases in pre-buckling region for clamped condition and decreases in
post-buckling region for simply supported condition. It was concluded that volume of SMA wires and rise in temperature were responsible for controlling the buckling and vibration response.

J.D. Yau [18] controlled the vibration of maglev (magnetically levitated) vehicle travelling over flexible guideway. The author made the simplified two degree of freedom model of maglev oscillator controlled by Proportional Integral (PI) controller for maglev vehicle moving on flexible guideway. Using this model, governing equations of motion were developed. These equations of motion were solved by incremental iterative approach. To control the structure, PI controller based on back propagation network called as neuro PI controller was proposed. The response of maglev vehicle travelling on concrete guideway, flexible guideway was found out. The training and testing of proposed model was done. It was concluded that larger response will be obtained on vehicle and guideway at resonance, when passage frequencies coincides with natural frequency. The neuro PI controller is superior to PI controller for simulating control behaviour of maglev oscillator.

Barbara Tiseo [22] et al have investigated compact, simple and light systems of SMA based Adaptive Tunable Dynamic Vibration Absorber (ATDVA). The experimentation was performed on two reference structures to check the capabilities of ATDVA. In first case, SMA wire of 1.2 mm was clamped at both the extremities of a circular steel frame. The device was bonded to a aluminium plate. In second case, fiberglass panel with 17 SMA wires embedded was used for experimentation. The effect of ATDVA was observed in both cases. In first case about 10 dB of energy was attenuated at targeted frequency and the result obtained was same as that of second case. The graph of current vs. frequency and temperature vs. frequency were plotted and discussed. The author has suggested the practical application of the SMA based ATDVA particularly at low vibration levels, which are reliable and shown good and predictable performance.

M.A.Ahmad et al. [36] have controlled the vibration of flexible manipulator system by microcontroller based input shaping. A single link flexible manipulator was considered in this work. The model was made up of aluminium of dimensions 900 x 19.008 x 3.004 mm. The dynamic behaviour of manipulator using assumes mode method was used as platform for test and evaluation of proposed control approach. The modeling of flexible manipulator system was used as a basis of
A simulation environment for development and assessment of control technique. The simulation was performed for flexible manipulator using MATLAB. They have proposed positive input technique shape, positive zero vibration technique (ZVD) shape and positive zero vibration-derivative-derivative shapes. The comparison of embedded input shaping was done with simulation results. The graphs of torque vs. time and frequency vs. amplitude for PZV, PZVD & PZVDD were plotted. The graph represents comparison of embedded PIC & MATLAB simulation for different order derivative. From this comparison, it was concluded that vibrations can be reduced by convolving the system with impulse sequence.

Sergio Bittanti et al. [45] have applied the gain-scheduled multi-objective approach to periodic active control of vibration in helicopters. The author reported that linear matrix inequality technique (LMI technique) have several advantages to face control problems in any flight conditions. The disturbance rejection problem in forward flight stated by previous researchers was studied. The mathematical modeling of rotor blade was done for active vibration control. They have proposed the multi-objective $H_\infty$ / Generalized $H_2$ approach based on linear parametrically varying concept (LPV) for active vibration control in helicopter and this approach is superior to other robust control technique.

M. Reza Bagerzadeh Karimi et al. [25] studied the vibration control of multi degree freedom structure under earthquake excitation using active and passive control. The investigation of 10-storey building for active vibration control was explained. The tune mass damper (TMD) was applied at lowest, middle and top point of building. The mathematical model of building was made in MATLAB. Fuzzy logic control was applied in active vibration control. The graph of displacement vs. time for active and passive vibration control of tenth floor was plotted for with and without TMD control. Finally, It was concluded that active control system is good as compared to passive control for different location of controller. FLC method proposed was found to be satisfactory.

### 2.1.4 A Brief Review on Structural Control

G. Song et al. [8] have focused on superior thermomechanical and thermoelectrical properties of Nitinol Shape Memory Alloy, viz., shape memory effect and pseudoelastic effect. SMAs have high damping capacity, high power
density, fatigue resistance and good durability. The vibration repression of civil structure due to unexpected severe loading towards structural safety was achieved by SMA. The application of SMAs in structure control was classified as active, semi-active and passive control. This paper represents review of SMA applications in civil structures viz., SMA bars for highway bridges, SMA wires recentering devices for civil buildings, isolation for ground excitation and SMA spring isolation for multi-degree frame structure. The paper also presents SMA connectors designed for high damping and deformation. To achieve the optimum performance in structural control, the combined advantages of martensite and austenite SMA’s are effectively monitored.

O. Ben Mekki et al. [9] had presented an approach to study damping vibration of stay cable in a cable-stayed bridge by using SMA energy dissipation devices with super-elastic hysteresis. The author has formulated mathematical model of cable with SMA damper & verified it to control the stay cable. The author determined the effect of length of cable, cross sectional area of damper, length of damper on vibration of stay cable. The largest response to control free vibration of stay cable was determined by SMA damper as well as tuned mass damper (TMD). The vibration decay speed of SMA control cable was better than TMD control cable. Finally, the comparison was made between TMD & SMA damper for cable with both end fixed. The author noticed that SMA in its non-optimum position suppresses the high free vibration of stay cable than TMD in optimum position.

E. Switonski, et al. [10] had studied the SMA absorber & magneto-rheological bearing for vibration control in manipulator mechanism. The mathematical model of shape memory alloy absorber was interpreted with brisben model for stress & strain at different SMA temperature. The authors have analyzed SMA absorber in APDL & effect of length of absorber on natural frequencies. The vibration control of primary system can be achieved by achieving the effect of detuning. It is feasible to obtain absorber length which allows detuning two or more natural frequencies. The procedure for eliminating resonance is specified by determining absorber length and SMA actuator dimensions. Author had studied the magneto-rheological bearing which was modeled & analyzed in two parts (rigid part and elastic part). It was concluded that the method of determining dynamic characteristics of manipulator mechanism with MRF bearing is quite simple in application.
2.1.5 A Brief Review on Effect of Smart Materials other than SMA in Vibration Control.

J. Fei [21] had suggested that the adaptive control technique is more suitable to control the vibration in presence of disturbance. The cantilever flexible beam was modelled in MATLAB. The PZT sensors and actuators were attached to the beam. The comparison of first three modes of flexible beam with and without actuators and sensors was made. Due to PZT beam, stiffness and natural frequency was increased. He has invented the adaptive control law to compensate non-linearity of system and increased control accuracy and stability. Using adaptive control method, displacement of beam at tip of beam was minimized in presence of disturbance. The advantage of sliding mode control is insensitivity to disturbance. Therefore, the integration of adaptive control method and sliding mode control method were done to add the advantage of both the control systems. The author concluded that the adaptive control with sliding mode control suppresses more vibration of cantilever beam compared with adaptive control without sliding mode.

K.B. Waghulde et al. [38] have presented the vibration control of cantilever smart beam by using piezoelectric actuator and sensors. The piezoelectric material was bonded to beam surface for experimentation. The experimental setup was consisting of bonded beam, LP filler, dSPACE and signal analyser. The system model fitting best to sensor response of white noise actuation was obtained through MATLAB. The results were obtained for with and without controller. The data of sensor after actuation without controller was passed through dSPACE controller for design purpose. This data was loaded in MATLAB. Finally, the graph of frequency vs. vibration amplitude was plotted for white noise input with and without active control. From experimentation, they concluded that 30% reduction in vibration for first mode response was achieved.

Hassan A. et al. [16] have studied the feasibility of applying sliding control to MR damper integrated with secondary suspension system of train which suppress vibration & improves ride control. The analytical model (including vehicle body, two trucks and four wheel sets) of railway vehicle suspension system was made with nine degrees of freedom. Here, four dampers which are placed on left and right side of each truck were used to control vertical pitch & roll vibration. The author proposed
MR damper model and sliding control mode which minimizes the car body vertical acceleration to meet comfortable ride criteria. The graphs of amplitude of vertical car body displacement and acceleration vs. train speed and amplitude of vertical car body displacement and acceleration vs. damping coefficient were plotted. Similarly, the effect of car body mass, stiffness coefficient and shifting of centre of gravity were discussed. He concluded that vibration control of train suspension system with semi-active controlled MR dampers is feasible and effective. Sliding mode control is more effective than LQG control.

2.1.6 Research Gap

According to the brief review of work, many researchers have worked on various combinations of shape memory alloys, its characteristics and performance in vibration control of machines and structures. The SMA was used in the form of wires, bars, composite or laminated beam using SMA wires. None of above research depicts the effect of NiTi thermally activated SMA spring in vibration control of cantilever beam.

2.1.7 Conclusion

Hence it was felt by researcher that study of NiTi SMA spring will be more useful to suppress the amplitude of vibration of the existing system, with variety of applications. Also it works on a wide range of frequency of excitation as per requirement. The mechanical system having mass and elasticity are capable to produce vibration and one cannot eliminate it completely. Finally the conventional system will not be more effective to maintain the standard of vibration as per I.S.O. (International Standard Organization) to the variety of application. In this case, NiTi springs will be more effective.

The system where factor of safety are more important as well as comfort parameters are of prime importance like aeroplane, helicopters, engine mounting, etc. Thus, the conventional system will not be applicable upto satisfaction. At that time, the NiTi SMA spring with absorber are more useful to maintain vibration standard and to avoid fatigue failure.

Also, as the NiTi SMA comes in the smart material group, it acts smartly as compared to the conventional system. The time amplitude response analysis for such type of material is of more importance for understanding the behaviour of NiTi SMA
response curves. The curves developed during this research process will be helpful for designers and practitioners working in the field of vibration and noise control.

Based on above research gap, researcher has finalized to study the vibration analysis of cantilever beam with NiTi shape memory alloy.