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Analytic Vector Fields on an Almost Hermite Manifolds

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Abstract: *This communication respectively deals with contravariant almost analytic vector fields and contravariant almost analytic vector fields on a Kaehler manifold admitting semi- symmetric metric connection. The nature and behavior of curvature tensor $\widetilde{K}(x, y, z)$ associated with semi-symmetric metric connection and also that of concircular curvature tensor $C(X, Y, Z)$ has also been studied.*

Keywords: Kaehler manifold, Hermite Manifold, semi-symmetric, curvature tensor, concircular curvature.

I. INTRODUCTION

Let us consider an almost analytic vector field V in an almost complex manifold then under such a consideration we shall have

(1.1) $L_V F = 0 \Rightarrow [V, \bar{X}] = [\overline{V, X}]$

Where

(1.2) $L_V F \overset{\text{def}}{=} [V, X]$ and L stands for the operation of Lie-derivative.

An almost Hermite manifold is said to be Kaehler manifold if the Riemannian connection ∇ satisfies

(1.3) $(\nabla_X F)(Y) = 0.$

Using (1.1) and (1.3) we arrive at the conclusion that in a Kaehler manifold, we shall have

(1.4) $\nabla_{\bar{X}} V = \overline{\nabla_X V}$.

It has been mentioned in [5] that a vector field V is said to be a killing vector or affine killing vector provided.

(1.5) $(L_V g)(X, Y) = 0,$

where, the vector field V is said to be affine vector if

(1.6) $(L_V g)(X, Y) = 0$

Where X and Y are arbitrary vector fields and K is a curvature tensor.

II. CONTRAVARIANT ALMLOST ANALYTIC VECTOR FIELD:

Let V be a contravariant almost analytic vector field then as per the provisons given in [6], we shall have

(2.1) $\bar{\nabla}_V X = \nabla_V X + \omega(X)V - g(V, X)\rho$

and

(2.2) $\tilde{\nabla}_X V = \nabla_X V + \omega(V)X - g(X, V)\rho$

Using (2.1) and (2.2), we get

(2.3) $[V, X]_s = (V, X) + \omega(X)V - \omega(V)X.$

(2.3) can alternatively be written in the following alternative form

(2.4) $T(V, X) = \omega(X)V - \omega(V)X$

where $T(V, X) = [V, X]_s - (V, X)$ and $[V, X]_s$ is the Lie-bracket with respect to the semi- symmetric connection $\widetilde{\nabla}$.

With the help of (2.3), we can get

(2.5) $[V, \bar{X}]_s = [V, \bar{X}] + \omega(\bar{X})V - \omega(V)\bar{X}$

And (2.6) $[\overline{V, X}]_s = [V, \bar{X}] + \omega(X)\bar{V} - \omega(V)\bar{X}.$

With the help of (2.5), (2.6) and (1.1), we get

(2.7) $[V, \bar{X}]_s = [\overline{V, X}]_s + \omega(\bar{X})V - \omega(X)V$

Using (2.7) we arrive at the following conclusion

(2.8) $F(X, \rho) = \omega(X)\bar{V}$

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where $F(X,\rho) = g(\bar{X},\rho)$.
In the light of all these observations, we can therefore state:

THEOREM (2.1):

An arbitrary almost analytic contravariant vector field V associated to the connection ∇ is almost analytic contravariant associated to the semi-symmetric metric connection $\tilde{\nabla}$ iff (2.8) holds.

With the help of (2.5) and (2.6), we can easily get

(2.9) $\bar{\nabla}_X V = (\tilde{\nabla}_V F)(X) + \bar{\nabla}_X V + \omega(X)\bar{V} - \omega(\bar{X})V$.

Using (2.9) we can write

(2.10) $(\tilde{\nabla}_X v)(Y) = v(\tilde{\nabla}_X Y) = (\tilde{\nabla}_X g)(V,Y) + g(\tilde{\nabla}_X V, Y) + g(V, \tilde{\nabla}_X Y)$

where (2.11) $v(Y) = g(V,Y)$

Using (2.10) and (2.11), we get

(2.12) $(\tilde{\nabla}_X v)(Y) = g(\tilde{\nabla}_X V, Y)$

where, we have taken into account the fact that

(2.13) $(\tilde{\nabla}_Z g)F(X,Y) = 0$.

Operating with g both sides of (2.9), we get

(2.14) $g(\tilde{\nabla}_X V, Y) = g((\tilde{\nabla}_V F)(X), Y) + g(\overline{\tilde{\nabla}_X V}, Y) + \omega(X) g(\bar{V}, Y) - \omega(\bar{X}) g(V,Y)$.

With the help of (2.12) and (2.14), we get

(2.15) $(\tilde{\nabla}_X v)(Y) = (\tilde{\nabla}_V F)(X,Y) - (\tilde{\nabla}_X v)(\bar{Y}) + \omega(X) g(\bar{V},Y) + \omega(\bar{X}) g(V,Y)$.

If v be assumed to the covariant almost analytic vector field with respect to semi- symmetric connection $\tilde{\nabla}$ then we shall have

(2.16) $v\left((\tilde{\nabla}_X F)(Y)\right) - (\tilde{\nabla}_Y F)(X) = (\tilde{\nabla}_X v)(Y) - (\tilde{\nabla}_X v)(\bar{Y})$

Provided

(2.17) $v(\bar{X}) v(Y) = v(X) v(\bar{Y})$.

Using (2.16) in (2.15), we get

(2.18) $2(\tilde{\nabla}_X v)(Y) = (\tilde{\nabla}_V {}'F)(X,Y) + (\tilde{\nabla}_V {}'F)(Y,V) + (\tilde{\nabla}_Y {}'F)(V,X) + \omega(X) g(\bar{V},Y) - \omega(\bar{X}) g(V,Y)$.

(2.18) can be written in the following alternative form

(2.19) $2(\tilde{\nabla}_{\bar{X}} v)(Y) = (\tilde{d}\,{}'F)(X,Y,V) + \omega(X) g(\bar{V},Y) - \omega(\bar{X}) g(V,Y)$.

With the help of (2.19), we can there state.

THEOREM (2.2):

If V is a contravariant almost analytic vector field with respect to the connection ∇ then we have

(2.20) $2(\tilde{\nabla}_{\bar{X}} v)(Y) = (\tilde{d}\,{}'F)(X,Y,V)$

Provided

(2.21) $g(X,\rho)\,{}'F(V,Y) = {}'F(X,\rho) g(V,Y)$.

III. CURVATURE TENSOR ASSOCIATED WITH SEMI-SYMMETRIC METRIC CONNECTION

It can easily be observed that the curvature tensor $\tilde{K}$ with respect to the semi-symmetric metric connection satisfies

(3.1) $(L_V \tilde{K})(X,Y,Z) + \tilde{K}(L_V(X,Y,Z)) + \tilde{K}(X, L_V Y, Z) + \tilde{K}(X,Y,L_V Z) = V[\omega(\rho)]\{g(Y,Z)X - g(X,Z)Y\} + \omega(\rho)\{(L_V g)(Y,Z)X + g(L_V Y, Z)X + g(Y, L_V Z)X + g(Y,Z)(L_V X) - (L_V g)(X,Z)Y - g(L_V X, Z)Y - g(X, L_V Z)Y - g(X,Z)(L_V Y)\} + (L_V K)(X,Y,Z) + K(L_V X, Y, Z) + K(X, L_V Y, Z) + K(X,Y,L_V Z)$.

Making an application of (1.2), (1.5) and (1.6) in (3.1), we get

(3.2) $(L_V \tilde{K})(X,Y,Z) + \tilde{K}([V,X],Y,Z) + \tilde{K}(X,[V,Y],Z) + \tilde{K}(X,Y,[V,Z]) = K([V,X],Y,Z) + K(X,[V,Y],Z) + K(X,Y,[V,Z]) + V[\omega(\rho)]\{g(Y,Z)X - g(X,Z)Y\} + \omega(\rho)\{g([V,Y],Z)X + g(Y,[V,Z])X - g([V,X],Z)Y - g(X,[V,Z])Y + g(Y,Z)[V,X] - g(X,Z)[V,Y]\}$.

Using provisions as have been mentioned in [7] we can easily got

(3.3) $(L_V\widetilde{K})(X,Y,Z) = K(X,Y,Z) + \omega(\rho)\{g(Y,Z)X - g(X,Z)Y\}$.

Using (3.3) in (3.2), we get

(3.4) $(L_V\widetilde{K})(X,Y,Z) = V[\omega(\rho)]\{g(Y,Z)X - g(X,Z)Y\}$.

With the help of (3.4), we easily derive the following

(3.5) $(L_V\widetilde{K})(\bar{X},\bar{Y},\bar{Z}) = V[\omega(\rho)]\{g(Y,Z)\bar{X} - g(X,Z)\bar{Y}\}$,

(3.6) $(L_V\widetilde{K})(\bar{X},Y,Z) = V[\omega(\rho)]\{g(Y,Z)\bar{X} - g(\bar{X},Z)Y\}$,

(3.7) $(L_V\widetilde{K})(X,\bar{Y},Z) = V[\omega(\rho)]\{g(\bar{Y},Z)X - g(X,Z)\bar{Y}\}$,

and (3.8) $(L_V\widetilde{K})(X,Y,\bar{Z}) = V[\omega(\rho)]\{g(Y,\bar{Z})X - g(X,\bar{Z})Y\}$.

Adding (3.6), (3.7), (3.8) and thereafter using (3.5), we get

(3.9) $(L_V\widetilde{K})(\bar{X},\bar{Y},\bar{Z}) = (L_V\widetilde{K})(\bar{X},Y,Z) + (L_V\widetilde{K})(X,\bar{Y},Z) + (L_V\widetilde{K})(X,Y,\bar{Z})$

and (3.10) $(L_V\widetilde{K})(X,Y,Z) = (L_V\widetilde{K})(\bar{X},\bar{Y},Z) + (L_V\widetilde{K})(\bar{X},Y,\bar{Z}) + (L_V\widetilde{K})(X,\bar{Y},\bar{Z})$

In the light of all these observations, we can therefore sate:

THEOREM (3.1):

If a contravariant vector field V is a killing vector field on an almost Hermite manifold then we shall always have (3.9) and (3.10).

Let us write

(3.11) $(L_V\widetilde{K})(\bar{X},Y,Z,T) \stackrel{\text{def}}{=} (L_V\widetilde{K})((X,\bar{Y},Z),T)$

where X, Y, Z and T are arbitrary vector fields.

Using (3.11) in (3.4), we get

(3.12) $(L_V\widetilde{K})(X,Y,Z,T) = V[\omega(\rho)]\{g(Y,Z)g(X,T) - g(X,Z)g(Y,T)\}$

Interchanging X, Y, Z, T cyclically in (3.12) we respectively get the following

(3.13) $(L_V\widetilde{K})(Y,Z,T,X) = V[\omega(\rho)]\{g(Z,T)g(Y,X) - g(X,Z)g(T,Y)\}$,

(3.14) $(L_V\widetilde{K})(Z,T,X,Y) = V[\omega(\rho)]\{g(T,X)g(Z,Y) - g(X,Z)g(T,Y)\}$,

And (3.15) $(L_V\widetilde{K})(T,X,Y,Z) = V[\omega(\rho)]\{g(X,Y)g(T,Z) - g(T,Y)g(X,Z)\}$

Subtracting (3.14) from (3.12) and (3.15) from (3.13), we get

(3.16) $(L_V\widetilde{K})(X,Y,Z,T) + (L_V\widetilde{K})(T,X,Y,Z) = (L_V\widetilde{K})(Y,Z,T,X) + (L_V\widetilde{K})(Z,T,X,Y)$

Therefore we can state.

THEOREM (3.2):

If the contravariant almost analytic vector field V be assumed to be a killing vector as well on an almost Hermite manifold then (3.16) always holds.

VI. SPECIFIC CURVATURE TENSOR

The concircular curvature tensor C(X,Y, Z) is given by [3]

(4.1) $C(X,Y,Z) = K(X,Y,Z) - \frac{r}{n(n-1)}\{g(Y,Z)X - g(X,Z)Y\}$

Taking the Lie-derivative of (4.1),we get

(4.2) $(L_VC)(X,Y,Z) + C(L_VX,Y,Z) + C(X,L_VY,Z) + C(X,Y,L_VZ) = (L_VK)(X,Y,Z) + K(L_VX,Y,Z) + K(X,L_VY,Z) + K(X,Y,L_VZ) - \left[\frac{r}{n(n-1)}\right]\{(L_Vg)(Y,Z)X + g(L_VY,Z)X + g(Y,L_VZ)X + g(Y,Z)(L_VX) - (L_Vg)(X,Z)Y - g(L_VX,Z)Y - g(X,L_VZ)Y - g(X,Z)(L_VY)\}$.

Using (1.2) in (4.2), we get

(4.3) $(L_VC)(X,Y,Z) + C([V,X],Y,Z) + C(X,[V,Y],Z) + C(X,Y,[V,Z]) = K([V,X],Y,Z) + K(X,[V,Y],Z) + K(X,Y,[V,Z]) - \left[\frac{r}{n(n-1)}\right]\{(L_Vg)(Y,Z)X + g([V,Y],Z)X + g(Y,[V,Z])X + g(Y,Z)[V,X] - (L_Vg)(X,Z)Y - g([V,X],Z)Y - g(X,[V,Z])Y - g(X,Z)[V,Y]\}$.

Using (4.1) in (4.3), we get

(4.4) $(L_V C)(X,Y,Z) = \left[\frac{r}{n(n-1)}\right]\{(L_V g)(X,Z)Y - (L_V g)(Y,Z)X\}$

We now put bars an X, Y and Z in (4.4) and get

(4.5) $(L_V C)(\bar{X},\bar{Y},\bar{Z}) = \left[\frac{r}{n(n-1)}\right]\{(L_V g)(X,Z)\bar{Y} - (L_V g)(Y,Z)\bar{X}\}$

With the help of (4.4), we can also have

(4.6) $(L_V C)(\bar{X},Y,Z) = \left[\frac{r}{n(n-1)}\right]\{(L_V g)(\bar{X},Z)Y - (L_V g)(Y,Z)\bar{X}\}$

(4.7) $(L_V C)(X,\bar{Y},Z) = \left[\frac{r}{n(n-1)}\right]\{(L_V g)(X,Z)\bar{Y} - (L_V g)(\bar{Y},Z)X\}$

and

(4.8) $(L_V C)(X,Y,\bar{Z}) = \left[\frac{r}{n(n-1)}\right]\{(L_V g)(X,\bar{Z})Y - (L_V g)(Y,\bar{Z})X\}$.

As per the provisons made in [3], we shall have

(4.9) $(L_V g)(\bar{X},\bar{Y}) = (L_V g)(X,Y)$.

Adding (4.6), (4.7), (4.8) and therefore using (4.5) and (4.9), we get

(4.10) $(L_V C)(\bar{X},\bar{Y},\bar{Z}) = (L_V C)(\bar{X},Y,Z) + (L_V C)(X,\bar{Y},Z) + (L_V C)(X,Y,\bar{Z})$

Again, if we put bars on X, Y and Z in (4.10) then we get

(4.11) $(L_V C)(X,Y,Z) = (L_V C)(\bar{X},\bar{Y},Z) + (L_V C)(\bar{X},Y,\bar{Z}) + (L_V C)(X,\bar{Y},\bar{Z})$

In the light of all these observations, we can therefore state:

THEOREM (4.1):

If V be a contravariant almost analytic as well as an affine vector field in an almost Hermite manifold then (4.10) and (4.11) always holds provided ($L_V g$) be assumed to be hybrid.

The concircular curvature tensor $\tilde{C}(X,Y,Z)$ with respect to Semi-symmetric metric connection satisfies

(4.12) $\tilde{C}(X,Y,Z) = C(X,Y,Z) + \omega(\rho)\{g(Y,Z)X - g(X,Z)Y\}$.

and this curvature tensor also satisfies

(4.13) (a) $\tilde{C}(\bar{X},\bar{Y},\bar{Z},\bar{u}) = \tilde{C}(X,Y,Z,u)$

(b) $\tilde{C}(X,Y,\bar{Z},\bar{u}) = \tilde{C}(\bar{X},\bar{Y},Z,u)$

where

(4.14) $\tilde{C}(X,Y,Z,u) = g(\tilde{C}(X,Y,Z),u)$

and X, Y, Z, u are arbitrary vector fields.

Taking the Lie –derivative of (4.12), we get

(4.15) $(L_V\tilde{C})(X,Y,Z) + \tilde{C}(L_V X,Y,Z) + \tilde{C}(X,L_V Y,Z) + \tilde{C}(X,Y,L_V Z) = (L_V C)(X,Y,Z) + C(L_V X,Y,Z) + C(X,L_V Y,Z) + C(X,Y,L_V Z) + V[\omega(\rho)]\{g(Y,Z)X - g(X,Z)Y\} + \omega(\rho)\{(L_V g)(Y,Z)X + g(L_V Y,Z)X + g(Y,L_V Z)X + g(Y,Z)(L_V X) - (L_V g)(X,Z)Y - g(L_V X,Z)Y - g(X,L_V Z)Y - g(X,Z)(L_V Y)\}$

Using (1.2) and (4.12) in (4.15), we get

(4.16) $(L_V\tilde{C})(X,Y,Z) = (L_V C)(X,Y,Z) - \omega(\rho)\{(L_V g)(X,Z)Y - (L_V g)(Y,Z)X\} + V\omega(\rho)\{g(Y,Z)X - g(X,Z)Y\}$.

Using (4.4) in (4.16), we get

(4.17) $(L_V\tilde{C})(X,Y,Z) = V[\omega(\rho)]\{g(Y,Z)X - g(X,Z)Y\}$.

With the help of (4.17), we can get the following

(4.18) $(L_V\widetilde{C})(\bar{X},\bar{Y},\bar{Z}) = V[\omega(\rho)]\{g(Y,Z)\bar{X} - g(X,Z)\bar{Y}\}$,

(4.19) $(L_V\tilde{C})(\bar{X},Y,Z) = V[\omega(\rho)]\{g(Y,Z)\bar{X} - g(\bar{X},Z)Y\}$,

(4.20) $(L_V\tilde{C})(X,\bar{Y},Z) = V[\omega(\rho)]\{g(\bar{Y},Z)X - g(X,Z)\bar{Y}\}$,

and (4.21) $(L_V\tilde{C})(X,Y,\bar{Z}) = V[\omega(\rho)]\{g(Y,\bar{Z})X - g(X,\bar{Z})Y\}$.

Adding (4.19), (4.20) and (4.21) and therefore using (4.18), we get

(4.22) $(L_V\widetilde{C})(\bar{X},\bar{Y},\bar{Z}) = (L_V\tilde{C})(\bar{X},Y,Z) + (L_V\tilde{C})(X,\bar{Y},Z) + (L_V\tilde{C})(X,Y,\bar{Z})$.

Further, on putting bars on X, Y and Z in (4.21), we get

(4.23) $\left(L_V\tilde{C}\right)(X,Y,Z) = (L_V\widetilde{C})(\bar{X},\bar{Y},Z) + (L_V\widetilde{C})(X,\bar{Y},\bar{Z}) + (L_V\widetilde{C})(\bar{X},Y,\bar{Z})$.

Therefore, we can state:

THEOREM (4.2):

If the semi-symmetric metric concircular curvature tensor $\widetilde{C}(X,Y,Z)$ in an almost Hermite manifold satisfies (4.24) $r = n(n-1)\omega(\rho)$(where, r is the scalar curvature) then we shall always have (4.22) and (4.23).

Let us write

(4.25) $\left(L_V\tilde{C}\right)(-X,Y,Z,T) = g\left(L_V\tilde{C}\right)\left((X,Y,Z),T\right)$.

Using (4.17) and (4.25), we get

(4.26) $\left(L_V\tilde{C}\right)(X,Y,Z,T) = V[\omega(\rho)]\{g(Y,Z)g(X,T) - g(X,Z)g(X,T)\}$.

Interchanging X, Y, Z, T respectively in (4.26),we get

(4.27) $\left(L_V\tilde{C}\right)(Y,Z,T,X) = V[\omega(\rho)]\{g(Z,T)g(Y,X) - g(Y,T)g(Z,X)\}$,

(4.28) $\left(L_V\tilde{C}\right)(Z,T,X,Y) = V[\omega(\rho)]\{g(T,X)g(Z,Y) - g(X,Z)g(T,Y)\}$,

and ,

(4.29) $\left(L_V\tilde{C}\right)(T,X,Y,Z) = V[\omega(\rho)]\{g(X,Y)g(T,Z) - g(T,Y)g(X,Z)\}$.

Subtracting (4.27) from (4.26) and (4.29) from (4.27), we get

(4.30) $\left(L_V\tilde{C}\right)(X,Y,Z,T) + \left(L_V\tilde{C}\right)(T,X,Y,Z) = \left(L_V\tilde{C}\right)(Y,Z,T,X) + \left(L_V\tilde{C}\right)(Z,T,X,Y)$.

With the help of all these observation, we can therefore state:

THEOREM (4.3):

The Lie-derivative of concircular curvature tensor $\widetilde{C}(X,Y,Z)$ on an almost Hermite manifold with respect to semi-symmetric metric connection satisfies (4.30).

V. CONTRAVARIANT ALMOST ANALYTIC VECTOR FIELD ON A KAEHLER MANIFOLD ADMITTING SEMI-SYMMETRIC METRIC CONNECTION:

Using (2.6), we get

(5.1) $\overline{\tilde{\nabla}_V X} - \overline{\tilde{\nabla}_X V} = \overline{\nabla_V X} + \omega(X)\bar{V} - \omega(V)\bar{X}$.

Using (2.5) in (5.1), we get

(5.2) $\tilde{\nabla}_V\bar{X} - \tilde{\nabla}_{\bar{X}}V = \nabla_V\bar{X} - \nabla_{\bar{X}}V + \omega(\bar{X})V - \omega(V)\bar{X}$.

With the help of (5.1), (5.2) and (1.4), we get

(5.3) $\tilde{\nabla}_{\bar{X}}V = \left(\tilde{\nabla}_V F\right)(X) + \overline{\tilde{\nabla}_X V} + \omega(X)\bar{V} - \omega(\bar{X})V$.

But we know that,

(5.4) $\left(\tilde{\nabla}_X F\right)(Y) = -\,\omega(Y)\bar{X} + g(X,Y)\bar{\rho} + \omega(\bar{Y})X - g(X,\bar{Y})\rho$.

Using (5.4) in (5.3), we get

(5.5) $\left(\tilde{\nabla}_{\bar{X}} V\right) = \overline{\tilde{\nabla}_X V} + g(V,X)\bar{\rho} - g(V,\bar{X})\rho$.

From (5.5), we get

(5.6) $\tilde{\nabla}_{\bar{X}} V = \overline{\tilde{\nabla}_X V}$

Provided

(5.7) $'F(X,V)\rho = g(V,X)\bar{\rho}$

where $'F(X,V) \stackrel{\text{def}}{=} g(\bar{X},V)$ and $\tilde{\nabla}$ is semi-symmetric metric connection.

Therefore we can state:

THEOREM (5.1):

If V be a contravariant almost analytic vector field in a Kaehler manifold associated with Riemannian connection ∇ then (5.6) holds provided (5.7) is true.

VI. CONCLUSION

The present communication has been divided in to five sections of which the first section is introductory. In the second section firstly we have established the necessary and sufficient condition under which an arbitrary almost analytic contravariant vector field associated to the connection ∇ is almost analytic contravariant associated to the semi-symmetric metric connection $\widetilde{\nabla}$ and subsequently we have established the relationship which is satisfied by the contravariant almost analytic vector field V with respect to the connection ∇. In the third section we have established the relationships which are satisfied by the contraviriant vector field V on an almost Hermite manifold if the contravariant vector field be assume to be a killing vector field. In the fourth section we have established the relationship which are satisfied by contravariant vector field V if this vector be assumed to be almost analytic and affine one and subsequently the relationship which hold has been deduced when the semi-symmetric concircular curvature tensor $\tilde{C}(X,Y,Z)$ be assumed to satisfy $r = n(n-1)\omega(\rho)$ (where r is the scalar curvature) in an almost Hermite manifold. In the fifth and the last section we have derived the relationship which are satisfied by the contravariant almost analytic vector field in a Kaehler manifold associated with the Riemannian connection ∇.

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