Int. J. Contemp. Math. Sciences, Vol. 6, 2011, no. 33, 1607 - 1617

M-Projective Curvature Tensor on Kaehlar Manifold

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Abstract

Properties of $M-$projective curvature tensor been studied on Kaehlar manifold with respect to recurrent and symmetric properties.

1. Introduction

We consider a $2n-$dimensional Kaehlar manifold M_{2n} with a vector valued linear function F and a Riemannian metric g which satisfies the following conditions:

1.1) $\bar{\bar{X}} = -I_{2n}$, where $F(X) = \bar{X}$.

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

1.3) ${}^1F(X,T) = g(\bar{X}, Y)$.

1.4) $(D_X F)Y = 0$, where D is the Riemannian connection.

If we define [1]

1.5) a) ${}^1H(Y, Z) = -\frac{1}{2} C_3^1 \overline{R(Y, Z)}$, **b)** ${}^*H(Y, Z) = -{}^1H(Y, \bar{Z})$

Then we have

1.6) a) ${}^1H(Y,Z) = S(Y,\bar{Z})$, **b)** ${}^*H(Y, Z) = -{}^1H(Y, \bar{Z}) = S(Y, Z)$

where R and S are the so called Riemannian curvature tensor and the Ricci tensor respectively.

The projective curvature tensor W, Conformal curvature tensor C, Conharmonic curvature tensor L, Concircular curvature tensor V, $H-$projective curvature tensor P, $H-$conharmonic curvature tensor T, $H-$Concircular curvature tensor K, Conharmonic* curvature tensor T^*, $H-$conformal (Bochner) curvature tensor B and the conformal* curvature tensor C^* are given on Kaehlar manifold respectively by;

1.7) $a)\ W(X,Y,Z) = R(X,Y,Z) - \frac{1}{2n-1}[S(Y,Z)X - S(X,Z)Y]$

$b)\ C(X,Y,Z) = R(X,Y,Z) - \frac{1}{2(n-1)}[S(Y,Z)X - S(X,Z)Y - g(X,Z)RY$

$+ g(Y,Z)RX] + \frac{r}{2(n-1)(2n-1)}[g(Y,Z)X - g(X,Z)Y]$

$c)\ L(X,Y,Z) = R(X,Y,Z) - \frac{1}{2(n-1)}[S(Y,Z)X - S(X,Z)Y - g(X,Z)RY$

$+ g(Y,Z)RX]$

$d)\ V(X,Y,Z) = R(X,Y,Z) - \frac{r}{2n(2n-1)}[g(Y,Z)X - g(X,Z)Y]$

$e)\ P(X,Y,Z) = R(X,Y,Z) - \frac{1}{2(n+1)}[S(Y,Z)X - S(X,Z)Y + S(X,\bar{Z})\bar{Y}$

$- S(Y,\bar{Z})\bar{X} + 2S(X,\bar{Y})\bar{Z}]$

$f)\ T(X,Y,Z) = R(X,Y,Z) - \frac{1}{2(n+2)}[S(Y,Z)X - S(X,Z)Y + S(\bar{Y},Z)\bar{X}$

$- S(\bar{X},Z)\bar{Y} + 2S(\bar{X},Y)\bar{Z} + g(Y,Z)RX - g(X,Z)RY + {}^1F(Y,Z)R\bar{X}$

$- {}^1F(X,Z)R\bar{Y} - 2\,{}^1F(X,Y)R\bar{Z}]$

$g)\ K(X,Y,Z) = R(X,Y,Z) - \frac{r}{4n(n+1)}[g(Y,Z)X - g(X,Z)Y + {}^1F(Y,Z)\bar{X}$

$- {}^1F(X,Z)\bar{Y} - 2\,{}^1F(X,Y)\bar{Z}]$

$h)\ T^*(X,Y,Z) = R(X,Y,Z) + \frac{r}{2(n-1)(2n-1)}[g(Y,Z)X - g(X,Z)Y]$

$i)\ B(X,Y,Z) = R(X,Y,Z) - \frac{1}{2(n+2)}[S(Y,Z)X - S(X,Z)Y - g(X,Z)RY$

$+ g(Y,Z)RX + S(X,\bar{Z})\bar{Y} - S(Y,\bar{Z})\bar{X} - {}^1F(X,Z)R\bar{Y}$

$+ {}^1F(Y,Z)R\bar{X} - 2\,{}^1F(X,Y)R\bar{Z} + 2S(X,\bar{Y},)\bar{Z}]$

$$+\frac{r}{4(n+1)(n+2)}[g(X,Z)Y-g(Y,Z)X-{}^{1}F(X,Z)\bar{Y}$$
$$+{}^{1}F(Y,Z)\bar{X}-{}^{1}F(X,Y)\bar{Z}]$$

$j)\quad C^{*}(X,Y,Z)=R(X,Y,Z)-\frac{1}{2(n-1)}[g(Y,Z)RX-g(X,Z)RY]$

$$+\frac{r}{2(n-1)(2n-1)}[g(Y,Z)X-g(X,Z)Y]$$

where r is the scalar curvature tensor.

A Kaehlar manifold is said to be recurrent if for a non-zero recurrence vector v, that satisfies.

1.8) $(D_U R)(X,Y,Z)=v(U)R(X,Y,Z)$, from which we have.

1.9) a) $(D_U S)(Y,Z)=v(U)S(Y,Z)$

b) $(D_U R)(Y,Z)=v(U)RY$, where $g(RY,Z)=S(Y,Z)$, and

1.10) $D_U r=v(U)r$

Also on a Kaehlar manifold ${}^{1}H$ is said to be recurrent if it satisfies.

1.11) $(D_U\,{}^{1}H)(X,Y)=v(U)\,{}^{1}H(X,Y)$

A Kaehlar manifold is said to be symmetric if it satisfies.

1.12) $(D_U R)(X,Y,Z)=0$

From which we have

1.13) a) $(D_U S)(Y,Z)=0$

b) $(D_U R)Y=0$, and

1.14) $D_U r=0$

If Q stands for the curvature tensor vide equations **a-j** of **1.7** then it is said that a Kaehlar manifold is $Q-$recurrent if it satisfies.

1.15) $(D_U Q)(X,Y,Z)=v(U)Q(X,Y,Z)$

for a non-zero recurrence vector v.

And it is said that a Kaehlar manifold is $Q-$symmetric If it satisfies.

1.16) $(D_U Q)(X,Y,Z)=0$

The $M-$projective curvature on tensor on a Kaehlar manifold is given by:

1.17) $M(X,Y,Z)=R(X,Y,Z)-\frac{1}{4(n-1)}[S(Y,Z)X-S(X,Z)Y$

$$-S(Y,\bar{Z})\bar{X}+S(X,\bar{Z})\bar{Y}]$$

2. M-projective recurrent Kaehlar manifold

A Kaehlar manifold is said to be M – projective recurrent if it satisfies.

2.1) $(D_U M)(X, Y, Z) = v(U) M(X, Y, Z)$

For a non zero recurrence vector v.

From **1.17** we have;

2.2) $(D_U M)(X, Y, Z) - v(U) M(X, Y, Z) = (D_U R)(X, Y, Z)$

$$-v(U)R(X, Y, Z) - \frac{1}{4(n-1)}[((D_U S)(Y, Z) - v(U)S(Y, Z))X$$

$$-((D_U S(X, Z) - v(U)S(X, Z))Y - ((D_U S(Y, \bar{Z})$$

$$-v(U)S(Y, \bar{Z})\bar{X} + ((D_U S)(X, \bar{Z}) - v(U)S(X, \bar{Z})\bar{Y}]$$

If the manifold is M – projective recurrent we have;

2.3) $(D_U R)(X, Y, Z) - v(U)R(X, Y, Z) - \frac{1}{4(n-1)}[((D_U S(Y, Z)$

$$-v(U)S(Y, Z))X - ((D_U S)(X, Z) - v(U)S(X, Z))Y$$

$$-((D_U S(Y, \bar{Z}) - v(U)S(Y, \bar{Z}))\bar{X} + ((D_U S)(X, \bar{Z})$$

$$-v(U)S(X, \bar{Z}))\bar{Y}] = 0$$

Contracting this equation with respect to X we get;

2.4) $\frac{n-2}{2(n-1)}((D_U S)(Y, Z) - v(U)S(Y, Z) = 0$

Hence we can state:

Theorem 2.1: A M – projective recurrent Kaehlar manifold M_{2n}, $n > 2$ is Ricci recurrent.

Theorem 2.2: A Kaehlar manifold M_{2n}, $n > 2$ M – projective current if and only if it is recurrent.

Theorem 2.3: A Flat Kaehlar manifold is M – projective recurrent if any only if it is Ricci recurrent.

Theorem 2.4: If on a Kaehlar manifold two of the following hold, the third also hold.

a. It is M – projective recurrent manifold.
b. It is recurrent manifold.
c. It is Ricci recurrent manifold.

Now barring Z in **2.4** and using **1.6.a** we get:

2.5) $\frac{n-2}{2(n-1)}((D_U\ {}^1H(Y, Z) - v(U)\ {}^1H(Y, Z) = 0$

Hence, we have;

Theorem 2.5: On an $M-$projective recurrent Kaehlar manifold M_{2n}, $n>2$, ${}^1H$ is recurrent.

From **1.17** and **1.7.d** we have;

2.6) $$M(X,Y,Z)=V(X,Y,Z)-\frac{1}{4(n-1)}[S(Y,Z)X-S(Y,Z)Y-S(Y,\bar{Z})\bar{X}+S(X,\bar{Z})\bar{Y}+\frac{r}{2n(2n-1)}[g(Y,Z)X-g(X,Z)Y]$$

From which we have:

2.7) $$\left(D_U M\right)(X,Y,Z)-v\left(U\right)M(X,Y,Z)=\left(D_U V\right)(X,Y,Z)$$
$$-v\left(U\right)V(X,Y,Z)-\frac{1}{4\left(n-1\right)}[\left(\left(D_U S\right)\left(Y,Z\right)-v\left(U\right)S\left(Y,Z\right)\right)X$$
$$-\left(\left(D_U S\right)\left(X,Z\right)-v\left(U\right)S\left(X,Z\right)\right)Y-\left(\left(D_U S\right)\left(Y,\bar{Z}\right)-v\left(U\right)S\left(Y,\bar{Z}\right)\right)\bar{X}$$
$$+\left(\left(D_U S\right)\left(X,\bar{Z}\right)-v\left(U\right)S\left(X,\bar{Z}\right)\right)\bar{Y}]+\frac{\left(D_U r-v\left(U\right)r\right)}{2n\left(2n-1\right)}\left[g\left(Y,Z\right)X-g\left(X,Z\right)Y\right]$$

Hence, we can state:

Theorem 2.6: On a Kaehlar manifold if any two of the following hold, the third also hold:

a. It is M-projective recurrent manifold.
b. It is Concircular recurrent manifold.
c. It is a Ricci recurrent manifold.

Similarly we can prove nine theorems analog to theorem **2.6** by simply replacing Concircular in part b of the theorem by projective, conformal, conharmonic, $H-$projective $H-$conformal, $H-$conharmonic, $H-$Concircular, Conharmonic $C*$, and Conformal*.

Now from **1.7.j** we can have:

2.8) $$\left(D_U C*\right)\left(X,Y,Z\right)-v\left(U\right)C*\left(X,Y,Z\right)=\left(D_U R\right)\left(X,Y,Z\right)$$
$$-v\left(U\right)R\left(X,Y,Z\right)-\frac{1}{2(n-1)}[g(Y,Z)((D_U R)X$$
$$-v(U)RX)-g(X,Z)((D_U R)Y-v(U)RY)]$$
$$+\frac{(D_U r-v(U)r)}{2(n-1)(2n-1)}[g(Y,Z)X-g(X,Z)Y]$$

If the manifold is Conformal* recurrent we have;

2.9) $(D_U R)(X,Y,Z) - v(U)R(X,Y,Z)$

$$-\frac{1}{2(n-1)}[g(Y,Z)((D_U R)X - v(U)RX)]$$

$$-g(X,Z)((D_U R)Y - v(U)RY)]$$

$$+\frac{(D_U r - v(U)r}{2(n-1)(2n-1)}[g(Y,Z)X - g(X,Z)Y] = 0$$

Contracting this equation with respect to X we get:

2.10) $\frac{2(n-1)}{2n-2}\ ((D_U S)(Y,Z) - v(U)S(Y,Z) = 0$

Hence a Conformal* recurrent Kaehlar manifold is Ricci recurrent.

But from **1.17** and **1.7.j** we have;

2.11) $M(X,Y,Z) = C^*(X,Y,Z) - \frac{1}{4(n-1)}[S(Y,Z)X$

$$-S(X,Z)Y - S(Y,\bar{Z})\bar{X} + S(X,\bar{Z})\bar{Y}] - \frac{1}{2(n-1)}[g(Y,Z)RX$$

$$-g(X,Z)RY] + \frac{r}{2(n-1)(2n-1)}[g(Y,Z)X - g(X,Z)Y]$$

From which we can get;

2.12) $(D_U M)(X,Y,Z) - v(U)M(X,Y,Z) = (D_U C^*)(X,Y,Z)$

$$-v(U)C^*(X,Y,Z) - \frac{1}{4(n-1)}[\ ((D_U S)(Y,Z) - v(U)S(Y,Z))X$$

$$-((D_U S)(X,Z) - v(U)S(X,Z))Y - ((D_U S)(Y,\bar{Z}) - v(U)S(Y,\bar{Z}))\bar{X}$$

$$+((D_U S)(X,\bar{Z}) - v(U)S(X,\bar{Z}))\bar{Y}] - \frac{1}{2(n-1)}[g(Y,Z)((D_U R)X$$

$$-v(U)RX) - g(X,Z)((D_U R)Y - v(U)RY)] + \frac{(D_U r - v(U)r)}{2(n-1)(2n-1)}[g(Y,Z)X$$

$$-g(X,Z)Y].$$

Therefore, we have in consequence of theorem **2.1** and equations **2.10** & **2.9**.

Theorem 2.7: A Kaehlar manifold $M_{2n}, n > 2$ is $M-$projective recurrent if and only if it is Conformal * recurrent.

Now from **1.7.d** we have:

2.13) $(D_U V)(X,Y,Z) - v(U)V(X,Y,Z) = (D_U R)(X,Y,Z)$

$$-v(U)R(X,Y,Z) - \frac{(D_U r - V(U)r)}{2n(2n-1)}[g(Y,Z)X - g(X,Z)Y]$$

If the manifold Concircular recurrent we have:

2.14) $(D_U R)(X,Y,Z) - v(U)R(X,Y,Z) = \frac{(D_U r - v(U)r)}{2n(2n-1)}[g(Y,Z)X - g(X,Z)Y]$

Contracting this equation with respect to X we obtain;

2.15) $\left(D_U S\right)(Y,Z) - v(U)S(Y,Z) = \frac{(D_U r - v(U)r}{2n} g(Y,Z)$

If $r = 0$, we have; $\left(D_U S\right)\left(Y,Z\right) - v\left(U\right)S\left(Y,Z\right) = 0$, which means that the manifold is Ricci-recurrent. But from **1.17** and **1.7.d** we can have:

2.16) $M(X,Y,Z) = V(X,Y,Z) - \frac{1}{4(n-1)}[S(Y,Z)X - S(X,Z)Y -$

$S(Y,\bar{Z})\bar{X} + S(X,\bar{Z})\bar{Y}] + \frac{r}{2n(2n-1)}[g(Y,Z)X - g(X,Z)Y]$

Form which we can get:

2.17) $(D_U M)(X,Y,Z) - v(U)M(X,Y,Z) - (D_U V)(X,Y,Z) - v(U)V(X,Y,Z)$

$- \frac{1}{4(n-1)}[\ ((D_U S)(Y,Z) - v(U)S(Y,Z))X - ((D_U S)(X,Z) - v(U)S(X,Z))Y$

$- ((D_U S)(Y,Z) - v(U)S(Y,\bar{Z}))\bar{X} + ((D_U S)(X,\bar{Z}) - V(U)S(X,\bar{Z}))\bar{Y}]$

$+ \frac{(D_U r - v(U)r)}{2n(2n-1)}[g(Y,Z)X - g(X,Z)Y]$

Hence, we have:

Theorem 2.8: A necessary and sufficient condition for a Kaehlar manifold M_{2n}, $n > 2$ of zero scalar curvature to be $M-$projective recurrent is that it is Concircular recurrent manifold.

Similarly we can prove :

Theorem 2.9: A necessary and sufficient condition for a Kaehlar manifold M_{2n}, $n > 2$ of zero scalar curvature to be $M-$projective recurrent is that it is $H-$Concircular manifold.

Theorem 2.10: A necessary and sufficient condition for a Kaehlar manifold M_{2n}, $n > 2$ of zero for curvature to be $M-$projective recurrent is that it is Conharmonic* recurrent manifold.

3. M-projective symmetric Kaehlar manifold

A Kaehlar manifold is said to be $M-$projective symmetric if it satisfies.

3.1) $\left(D_U M\right)\left(X, Y, Z\right) = 0$.

It is clear that every symmetric Kaehlar manifold is $M-$projective symmetric.

From **1.17** and **3.1** we have if the manifold is $M-$projective symmetric,

3.2) $(D_U R)(X, Y, Z) - \frac{1}{4(n-1)}[(D_U S)(Y, Z)X - (D_U S)(X, Z)Y - (D_U S)(X, \bar{Z})\bar{Y}$

$+ (D_U S)(X, \bar{Z})\bar{Y}] = 0$

Contracting this equation with respect to X we get;

3.3) $\frac{n-2}{2(n-1)}(D_U S)(Y, Z) = 0$.

If $n \neq 2$, then the manifold is Ricci-Symmetric. That is, equations **1.13** and **1.14** holds. Hence, we have that,

Theorem 3.1: A necessary and sufficient condition for a $M-$projective symmetric Kaehlar manifold to be symmetric is that it is Ricci-symmetric.

Theorem 3.2: An $M-$projective symmetric Kaehlar manifold, M_{2n}, $n > 2$ is Ricci-symmetric.

Theorem 3.3: Every $M-$projective symmetric Kaehlar manifold M_{2n}, $n > 2$ is symmetric.

Theorem 3.4: On $M-$projective symmetric Kaehlar manifold M_{2n}, $n > 2$, the scalar curvature is constant.

Now using Bianchi identify on **3.2** we have:

3.4) $(D_X R)(V, Y, Z) - (D_Y R)(U, X, Z) - \frac{1}{4(n-1)}[(D_U S)(Y, Z)X - (D_U S)(X, Z)Y$

$- (D_U S)(Y, \bar{Z})\bar{X} + (D_U S)(X, \bar{Z})\bar{Y}] = 0$

Contracting this equation with respect to U we get;

3.5) $\frac{1}{4(n-1)}[(4n-5)((D_X S)(Y, Z) - (D_Y S)(Y, Z)) + (D_{\bar{X}}\,{}^1H)(Y, Z) -$

$(D_{\bar{Y}}\,{}^1H)(X, Z))] = 0$

Hence we can state:

Theorem 3.5: On an $M-$projective symmetric Kaehlar manifold we have equation **3.5**.

Theorem 3.6: On an $M-$projective symmetric Kaehlar manifold, the first covariant derivative of the Ricci tensor is symmetric if and only if $(D_{\bar{X}}\,{}^1H)(Y, Z) = (D_{\bar{Y}}\,{}^1H)(X, Z)$

Theorem 3.7: Every Einstein $M-$Projective symmetric Kaehlar manifold is symmetric.

Proof: For an Einstein manifold the scalar curvature is constant and the Ricci tensor is given by:

3.6) $S(X,Y)=\frac{r}{2n}g(X,Y)$. Therefore, we have; $(D_U S)(X,Y)=0$. Hence the statement follows from **3.2**.

Theorem 3.8: Every recurrent $M-$projective symmetric Kaehlar manifold is $M-$protectively flat.

The proof is obvious.

Theorem 3.9: An $M-$projective symmetric Kaehlar manifold is Ricci-recurrent if and only if;

3.7) $(D_U R)(X,Y,Z)+v(U)\left[M(X,Y,Z)-R(X,Y,Z)\right]=0$

Proof: If the manifold is Ricci recurrent then we have in consequence of **1.9** and **3.2**.

3.8) $(D_U R)(X,Y,Z)-\frac{v(U)}{4(n-1)}[S(Y,Z)X-S(X,Z)Y-S(Y,Z)\overline{X}+S(X,Z)\overline{Y}]=0$

Using **1.17** and **3.8** we get **3.7**.

Conversely, if **3.7** is true then using it on **3.2** we get; $(D_U S)(Y,Z)=v(U)S(Y,Z)$. Hence we have the statement.

Theorem 3.10: A recurrent Einstein $M-$projective symmetric space is flat .

Proof: For an Einstein manifold we have:

3.9) $(D_U M)(X,Y,Z)=(D_U R)(X,Y,Z)$.

If the manifold is $M-$projective recurrent we have for a non-zero recurrence vector v. $(D_U M)(X,Y,Z)=v(U)M(X,Y,Z)$. By theorem **2.9** we have; $(D_U M)(X,Y,Z)=v(U)R(X,Y,Z)$. Since the manifold is M-projective symmetric we have; $v(U)R(X,Y,Z)=0$. Hence we have the statement, since v non-zero.

Now differentiating **2.16** covariant we get;

3.10) $$(D_U M)(X,Y,Z)=(D_U V)(X,Y,Z)-\frac{1}{4(n-1)}[(D_U S)(Y,Z)X-(D_U S)(X,Z)Y$$
$$-(D_U S)(Y,\overline{Z})\overline{X}-(D_U S)(X,\overline{Z})\overline{Y}]+\frac{D_U r}{2n(2n-1)}[g(Y,Z)X-g(X,Z)Y]$$

Therefore we can have in consequence of **1.13**, **1.14**, **1.16** and **3.1**.

Theorem 3.11: On a Kaehlar manifold if any two of the following hold, the third also hold.

a. It is $M-$projective symmetric manifold .

b. It is Concircular symmetric manifold.

c. It is Ricci symmetric manifold.

Similarly we can prove nine theorems analog to theorem **3.10** by simply replacing Concircular in pat **b** of the theorem by projective, conformal, $H-$conharmonic, $H-$Concircular, Conharmonic*, and Conformal*.

Theorem 3.12: If an $M-$projective symmetric Kaehlar manifold is Concircular recurrent and Ricci- recurrent under the same recurrence Vector, then it is $M-$protectively flat.

Proof: Using the facts given in theorem **2.10** we get;

$$\textbf{3.11)}\ V(X,Y,Z)-\frac{1}{4(n-1)}[S(Y,Z)X-S(X,Z)Y-S(Y,\bar{Z})\bar{X}+S(X,\bar{Z})\bar{Y}]$$

$$+\frac{r}{2n(2n-1)}[g(Y,Z)X-g(X,Z)Y]=0$$

Hence the result follows from **3.16**.

Theorem 3.13: If a Kaehlar manifold is Concircular symmetric, $M-$projective recurrent and Ricci-recurrent under the same recurrent vector, then it is Concircular flat.

The proof is similar to the proof of the above theorem.

Theorem 3.14: If an $M-$projective symmetric Kaehlar manifold is Concircular symmetric and Ricci-recurrent under the same recurrent vector, then the $M-$projective and the Concircular tensors coincide.

Proof: Using the fact given in theorem **3.10** we get :

$$\textbf{3.12)}\ -\frac{1}{4(n-1)}[S(Y,Z)X-S(X,Z)Y-S(Y,\bar{Z})\bar{X}+S(X,\bar{Z})\bar{Y}]$$

$$+\frac{r}{2n(2n-1)}[h(Y,Z)X-g(X,Z)Y]=0$$

Hence the statement follows from **3.9**.

Similarly we can prove three theorem analog to the above three theorems by simply replacing Concircular in each one by projective, conformal, conharmonic , $H-$projective, $H-$conformal, $H-$Conharmonic, $H-$Concircular, Conharmonic*, and Conformal *.

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Received: March, 2011