SOME CONDITIONS ON *K*-CONTACT MANIFOLD ADMITTING QUARTER-SYMMETRIC METRIC CONNECTION

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Abstract: *Inthispaperweconsideraquarter-symmetricmetricconnectionin a K-Contact manifold and study the second order parallel tensor in a K-Contact manifold with respect to the quarter-symmetric metric connection. Then Ricci semisymmetricK-Contactmanifoldwithrespecttothequarter-symmetricmetricconnectionisconsidered.Nextξ-concircularlyflatK-Contactmanifoldswith respect to the quarter-symmetric metric connection. Further, the authors study K-Contactmanifoldssatisfyingthecondition$\tilde{C}(\xi,Y)\cdot\tilde{S}=0$,where$\tilde{C},\tilde{S}$arethe concircular curvature tensor and Ricci tensor respectively with respect to the quarter-symmetric metricconnection.*

***KeyWords:K*-Contactmanifold,Riccisemisymmetricmanifold,ξ-Concircularly flat, quarter-symmetric metricconnection.**

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1. INTRODUCTION

Alinearconnection$\tilde{\nabla}$in an n-dimensional differentiablemanifold is said to be a quarter-symmetric connection [9] if its torsion tensor T is of the form

$$T(B,D) = \tilde{\nabla}_B D - \tilde{\nabla}_D B - [B,D]$$

$$= \eta(D)\emptyset B - \eta(B)\emptyset D, \qquad (1.1)$$

where η is a 1-form and $\emptyset$is a tensor of type (1, 1). In particular, if $\emptyset B$= B, then the quarter-symmetric connection reduces to the semi-symmetric connection [8]. Thus the notion ofquarter-symmetricconnectiongeneralizestheideaofthesemi-symmetricconnection.And ifquarter-symmetriclinearconnection$\tilde{\nabla}$ satisfies the condition

$$(\tilde{\nabla}_B g)(D,F)=0,$$

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for all B, D, $F \in \chi(M)$, where $\chi(M)$ is the Lie algebra of vector fields on the manifold M, then $\widetilde{\nabla}$ is said to be a quarter-symmetric metric connection.

A transformation of an n-dimentional Riemmannian manifold M is said to be a concircular transformation if it transforms every geodesic circle of M into a geodesic circle. Aconcircular transformation is always a conformal transformation. Here we mean a geodesic circle by a curve in M whose first curvature is constant and the second curvature is identically zero. thus, the geometry of concircular transformations is a generalization of inversive geometry in the sense that the change of metric is more general than that induced by a circle preserving diffeomorphism. An important invariant of a concircular transformation is the curvcature tensor C, definedby

$$C(B,D)F = R(B,D)F - \frac{r}{n(n-1)}[g(D,F)B - g(B,F)D] \tag{1.2}$$

where $R(B,D)F$ is the Riemannian curvature tensor and r is the scalar curvature.

In the present paper, we study quarter-symmetric metric connection in a K-Contact manifold. The paper is organized is as follows. In Section 2, we have preliminaries of K-Contact manifold. In Section 3, we discuss the expressions for $\widetilde{R}(B,D)F$. In Section 4, we study the Second order Parallel Tensor in K-Contact manifolds with respect to quarter-symmetric metric connection. Section 5 is devoted study the Ricci Semisymmetric K-Contact manifold with respect to quarter-symmetric metric connection. In section 6, we discuss the ξ- concircularly Flat K-Contact manifolds. In section 7, we study K-Contact manifolds Satisfying the $\widetilde{C}(\xi,D)\cdot\widetilde{S}=0$ and Section 8 is devoted study $\emptyset$-Projectively Flat K-Contact manifold with respect to quarter-symmetric metricconnection.

2.PRELIMINARIES

An n-dimensional differentiable manifold M is said to have an almost contact structure $(\emptyset,\xi,\eta)$ if it carries a tensor field $\emptyset$ of type $(1,1)$, a vector field ξ and a 1-form η on M respectively such that,

$$\emptyset^2 = -I + \eta \otimes \xi, \quad \eta(\xi)=1, \quad \eta \circ \emptyset = 0, \quad \emptyset\xi = 0. \tag{2.1}$$

Thus a manifold M equipped with this structure is called an almost contact manifold and is denoted by $(M,\emptyset,\xi,\eta)$. If g is a Riemannian metric on an almost contact manifold M such that,

$$g(\emptyset B,\emptyset D) = g(B,D) - \eta(B)\eta(D), \quad g(B,\xi) = \eta(B), \tag{2.2}$$

$$g(B,\emptyset D) = -g(\emptyset B, D), \tag{2.3}$$

where B, D are vector fields defined on M, then M is said to have an almost contact metric structure $(\emptyset, \xi, \eta, g)$ and M with this structure is called an almost contact metric manifold andisdenotedby$(M, \emptyset, \xi, \eta, g)$.

If on $(M, \emptyset, \xi, \eta, g)$ the exterior derivative of 1-form η satisfies,

$$d\eta(B,D)=g(B,\emptyset D), \tag{2.4}$$

then$(\emptyset,\xi,\eta,g)$issaidtobeacontactmetricstructureand$M$equippedwithacontactmetric structure is called contact metricmanifold.

If moreover ξ is killing vector field, then M is called a K-Contact Riemannian manifold [2],[16]. A K-Contact Riemannian manifold is called Sasakian [2], if the relation

$$(\nabla_B \emptyset)D=g(B,D)\xi-\eta(D)\emptyset B \tag{2.5}$$

holds, where ∇ denotes the operator of covariant differentiation with respect to$g$.

In a K-Contact manifold M, the following relations holds;

$$\nabla_B\xi = -\emptyset B, \tag{2.6}$$

$$g(R(\xi, B)D,\xi) = g(B, D) - \eta(B)\eta(D), \tag{2.7}$$

$$R(\xi,B)\xi = -B+ \eta(B)\xi, \tag{2.8}$$

$$S(B,\xi) = (n-1)\eta(B), \tag{2.9}$$

$$S(\emptyset B, \emptyset D) = S(B,D)-(n-1)\eta(B)\eta(D), \tag{2.10}$$

for any vector fields B, D and$F$. Where R and S are the Riemannian curvature tensor and the Ricci tensor of Mrespectively.

Definition2.1.*AtensorTofsecondorderissaidtobeasecondorderparalleltensorif*$\nabla T=0$ *,where*∇*denotestheoperatorofcovariantdifferentiationwithrespecttothemetrictensor* g.

Definition 2.2. *A K-Contact manifold M is said to be locally projective $\emptyset$-symmetric if*

$$\emptyset^2\,((\nabla_W P)(B, D) F) = 0,$$

forallvectorfieldsB,D,FandWorthogonaltoξ,wheretheprojectivecurvaturetensorPis givenby

$$P(B,D)F = R(B,D)F - \frac{1}{n(n-1)}[S(D,F)B - S(B,F)D]$$

Here R is the Riemannian curvature tensor andS is the Ricci tensor.

Definition 2.3. *A K-Contact manifold M is said to be locally projective ∅-symmetric with respect to the quarter-symmetric metric connection if*

$$\emptyset^2((\tilde{\nabla}_W\tilde{P})(B,D)F)=0,$$

forallvectorfields B,D,F,W *orthogonalto* ξ *where* $\tilde{P}$ *istheprojectivecurvaturetensorwith respect to the quarter-symmetric metric connection given by*

(2.11) $$\tilde{P}(B,D)F = \tilde{R}(B,D)F - \frac{1}{n(n-1)}[\tilde{S}(D,F)B - \tilde{S}(B,F)D]$$

3.EXPRESSIONOF $\tilde{R}(X,Y)Z$

A quarter-symmetric metric connection $\tilde{\nabla}$ in a K-Contact manifold is given by [15]

(3.1) $$\tilde{\nabla}_B D=\nabla_B D-\eta(B)\emptyset D.$$

Therefore equation (3.1) is the relation between Levi-Civita connection and the quarter- symmetric metric connection on a *K*-Contactmanifold.

A relation between the curvature tensor of *M* with respect to the quarter-symmetric metric connection $\tilde{\nabla}$ and the Levi-Civita connection ∇ is givenby

(3.2) $$\tilde{R}(B,D)F= R(B,D)F-2g(B,\emptyset D)\emptyset F+[\eta(B)g(D,F) - \eta(D)g(B,F)]\xi + [\eta(D)B- \eta(B)D]\eta(F),$$

where $\tilde{R}$ and R aretheRiemanniancurvatureoftheconnections $\tilde{\nabla}$ and ∇ respectively.

From (3.2), it follows that

(3.3) $$\tilde{S}(D,F)=S(D,F)-g(D,F)+n\eta(D)\eta(F),$$

where $\tilde{S}$ and S aretheRiccitensorsoftheconnections $\tilde{\nabla}$ and ∇ respectively

By making use of (3.2), we obtain

(3.4) $$\tilde{R}(\xi,D)F = 2[g(D,F)\xi - \eta(F)D]$$

and

(3.5) $$\tilde{R}(B,D)\xi = 2[\eta(D)B - \eta(B)D],$$

where $B, D \in \chi(M)$.

4. THESECONDORDERPARALLELTENSORIN*K*-CONTACTMANIFOLDS

Suppose α be a second order parallel tensor with respect to the quarter-symmetric metric connection,thatis$\tilde{\nabla}\alpha=0$.Thenwehave

$$\alpha\left(\tilde{R}(W,B)D,F\right)+\alpha\left(D,\tilde{R}(W,B)F\right)=0 \tag{4.1}$$

for all vector fields $B, D, F, W \in \chi(M)$.

Taking W=D=F=ξ in (4.1), we can write

$$\alpha(\xi,\tilde{R}(\xi,B)\xi)=0.$$

Using(3.4),wecanwrite

$$\alpha(B,\xi)-g(B,\xi)\alpha(\xi,\xi)=0. \tag{4.2}$$

Differentiating (4.2) covariantly along D, we get

$$[g(\tilde{\nabla}_D B,\xi)+g(B,\tilde{\nabla}_D\xi)]\alpha(\xi,\xi)+2g(B,\xi)\alpha(\tilde{\nabla}_D\xi,\xi)$$
$$-[\alpha(\tilde{\nabla}_D B,\xi)+\alpha(B,\tilde{\nabla}_D\xi)]=0. \tag{4.3}$$

Putting$B=\tilde{\nabla}_D B$in(4.2),weget

$$g(\tilde{\nabla}_D B,\xi)\alpha(\xi,\xi)-\alpha(\tilde{\nabla}_D B,\xi)=0. \tag{4.4}$$

Using (4.4) in (4.3), we get

$$g(B,\tilde{\nabla}_D\xi)\alpha(\xi,\xi)+2g(B,\xi)\alpha(\tilde{\nabla}_D\xi,\xi)-\alpha(B,\tilde{\nabla}_D\xi)=0. \tag{4.5}$$

By (3.1) it follows from (4.5) that

$$g(B,\varnothing D)\alpha(\xi,\xi)+2g(B,\xi)\alpha(B,\xi)\alpha(\varnothing D,\xi)-\alpha(B,\varnothing D)=0. \tag{4.6}$$

Taking $B=\varnothing D$in (4.2), we obtain

$$\alpha(\varnothing D,\xi)=0, \tag{4.7}$$

using (4.7) in (4.6)

$$g(B,\varnothing D)\alpha(\xi,\xi)-\alpha(B,\varnothing D)=0. \tag{4.8}$$

Replace D by ϕD in (4.8) and using (4.2) and (2.1)

$$g(B,D)\alpha(\xi,\xi)=\alpha(B,D)+\eta(D)[\alpha(B,\xi)-g(B,\xi)\alpha(\xi,\xi)]$$

(4.9) $$\alpha(B,D)=\alpha(\xi,\xi)g(B,D).$$

Theorem4.1. *OnaK-Contactmanifold,admittingaquarter-symmetricmetricconnection,a secondordersymmetricparalleltensorwithrespecttothequarter-symmetricmetricconnection is a constant multiple of the associated metrictensor.*

5. RICCI SEMISYMMETRIC*K*-CONTACTMANIFOLDS

Here we investigate about Ricci semisymmetric K-Contact manifold with respect to the quarter-symmetricmetricconnection,thatis,thecurvaturetensorsatisfiesthecondition

$$(\tilde{R}(B,D)\cdot\tilde{S})(F,V)=0,$$

here$\tilde{R}(B,D)$isthederivationofthetensoralgebraateachpointofthemanifold,whichimplies

(5.1) $$\tilde{S}(\tilde{R}(B,D)F,V)+\tilde{S}(F,\tilde{R}(B,D)V)=0.$$

Using (3.3) in (5.1) which leads to

$$S(\tilde{R}(B,D)F,V)-g(\tilde{R}(B,D)F,V)+n\eta((\tilde{R}(B,D)F))\eta(V)$$

(5.2) $$+S(F,\tilde{R}(B,D)V)-g(F,\tilde{R}(B,D)V)+n\eta(F)\eta(\tilde{R}(B,F)V)=0.$$

Taking $B=F=\xi$ in (5.2) and using (3.4) , (2.8) and (2.9), we have

$$2[(n-1)\eta(D)\eta(V)-S(D,V)]-2[\eta(D)\eta(V)-g(D,V)]$$
$$+2(n-1)[g(D,V)-\eta(D)(V)]-2[g(D,V)-\eta(D)\eta(V)]$$
(5.3) $$-2[g(D,V)-\eta(D)\eta(V)]+2n[g(D,V)-\eta(D)\eta(V)]=0,$$

which implies

(5.4) $$S(D,V)=(2n-1)g(D,V)-n\eta(D)\eta(V),$$

then by (3.3) we have

(5.5) $$\tilde{S}(D,V)=(2n-3)g(D,V).$$

Theorem5.2.*AK-ContactmanifoldisRiccisemisymmetricwithrespecttothequarter-symmetricmetricconnectionifandonlyifthemanifoldisanEinsteinmanifoldwithrespect to the Levi-Civitaconnection*

6. ξ- CONCIRCULARLY FLAT*K*-CONTACTMANIFOLDS

Definition6.1.*AmanifoldMissaidtobeξ-concircularlyflatifthefollowingrelationholds:*

(6.1) $$C(B,D)\xi=0$$

for any vector fields B,D∈χ(M), and C is the concircular tensor defined by (1.2)

Herewestudyξ-concircularlyflat$K$-Contactmanifoldswithrespecttothequarter-symmetric metricconnection$\tilde{\nabla}$.Thenfrom(1.2),wehave

(6.2) $$\tilde{R}(B,D)\xi-\frac{\tilde{r}}{n(n-1)}[g(D,\xi)B-g(B,\xi)D]=0,$$

for all vector fields $B,D,F\in\chi(M)$.

Using (3.5) and (6.2) we have

(6.3) $$[2-\frac{\tilde{r}}{n(n-1)}][\eta(D)B-\eta(B)D]=0$$

Since $\eta(D)B-\eta(B)D\neq0$,then

(6.4) $$\tilde{r}=2n(n-1).$$

Conversely, if the relation (6.4) satisfies. Therefore, using (3.5) we obtain

(6.5) $$\tilde{R}(B,D)\xi-\frac{\tilde{r}}{n(n-1)}\left[g(D,\xi)B-g(B,\xi)D\right]=0,$$

thatis$\tilde{C}(B,D)\xi=0$.

By the above discussions we can state the following theorem

Theorem 6.1. *A K-Contact manifold admitting quarter-symmetric metric connection is ξ-concircularlyflatwithrespecttothequarter-symmetricmetricconnectionifandonlyifthe scalarcurvatureisconstantwithrespecttoquarter-symmetricmetricconnection.*

7. *K*-CONTACTMANIFOLDSSATISFYINGTHE$\tilde{C}(\xi,D)\cdot\tilde{S}=0$

ConsideraK-ContactmanifoldMsatisfyingthecondition$\tilde{C}(\xi,D)\cdot\tilde{S}=0$withrespectto quarter-symmetricmetricconnection.Now$\tilde{C}(\xi,D)\cdot\tilde{S}=0$implies

(7.1) $$\tilde{S}(\tilde{C}(\xi,D)F,V)+\tilde{S}(F,\tilde{C}(\xi,D)V)=0,$$

for any vector fields $D,F,V\in\chi(M)$. Using (1.2) and (3.4) we obtain from (7.1) that

$$[2-\frac{\tilde{r}}{n(n-1)}][g(D,F)\tilde{S}(\xi,V)-\eta(F)\tilde{S}(D,V)+g(D,V)\tilde{S}(\xi,F)-\eta(V)\tilde{S}(D,F)]=0. \quad (7.2)$$

Substituting $F=\xi$ in (7.2) and using (2.9) we have

$$[2-\frac{\tilde{r}}{n(n-1)}][2(n-1)g(D,V)-\tilde{S}(D,V)=0. \quad (7.3)$$

Now using (3.3) in (7.3),we get

$$[2-\frac{\tilde{r}}{n(n-1)}][-S(D,V)+(2n-1)g(D,V)-n\,\eta(D)\eta(V)]=0. \quad (7.4)$$

Which implies either

$$\tilde{r}=2n(n-1) \quad (7.5)$$

or

$$S(D,V)=(2n-1)g(D,V)-n\eta(D)\eta(V). \quad (7.6)$$

Therefore, the manifold M is an η- Einstein manifold provided that the characteristic vector field ξ is harmonic.

Conversely, if we take $\tilde{r}=2n(n-1)$, then from (1.2) and (3.4)

$$\tilde{C}(\xi,D)F=0. \quad (7.7)$$

Thusitisclearthat$\tilde{C}(\xi,D)\cdot\tilde{S}=0$foranyvectorfields$D\in\chi(M)$.
Also assume that the relation (7.6) holds. Then using (7.6) and (3.3) yields

$$\tilde{S}(D,V)=2(n-1)g(D,V). \quad (7.8)$$

Thus we can state the following theorem.

Theorem7.4. *AK-Contactmanifoldadmittingquarter-symmetricmetricconnectionis* $\tilde{\nabla}$ *satisfiesthecondition* $\tilde{C}(\xi,D)\cdot\tilde{S}=0$ *ifandonlyifeitherthemanifoldisEinsteinprovidedthat thecharacteristicvectorfieldξisharmonicorthescalarcurvatureisconstantwithrespectto quarter-symmetric metricconnection.*

8. ∅-PROJECTIVELY FLAT K-CONTACT MANIFOLD

Definition 8.1. An n-dimentional differentiable manifold (M^n, g) satisfies the equation

(8.1) $$\emptyset^2(P(\emptyset B, \emptyset D)\emptyset F) = 0,$$

Is called ∅-projective flat. We define an n-dimentional *K*-Contact manifold is said to be ∅-projective flat with respect to the quarter-symmetric metric connection if it satisfies

(8.2) $$\emptyset^2(\tilde{P}(\emptyset B, \emptyset D)\emptyset F) = 0,$$

where $\tilde{P}$ is the projective curvature tensor of the manifold.

Suppose M^n is ∅-projectively flat *K*-Contact manifold with respect to quarter-symmetric metric connection. It is easy to see that $\emptyset^2(\tilde{P}(\emptyset B, \emptyset D)\emptyset F) = 0$ if and only if

(8.3) $$g(\tilde{P}(\emptyset B, \emptyset D)\emptyset F, \emptyset W) = 0,$$

for any $B, D, F, W \in TM$.
So by the use of (2.11) ∅-projectively flat means

(8.4) $$g(\tilde{R}(\emptyset B, \emptyset D)\emptyset F, \emptyset W) = \frac{1}{n-1}[\tilde{S}(\emptyset D, \emptyset F)g(\emptyset B, \emptyset W) - \tilde{S}(\emptyset B, \emptyset Z)g(\emptyset D, \emptyset W)],$$

which on using equations (3.2) and (3.3), we get

(8.5) $$g(R(\emptyset B, \emptyset D)\emptyset F, \emptyset W) - 2g(\emptyset B, D)g(F, \emptyset W) = \frac{1}{n-1}[S(\emptyset D, \emptyset F)g(\emptyset B, \emptyset W) - g(\emptyset D, \emptyset F)g(\emptyset B, \emptyset W) - S(\emptyset B, \emptyset F)g(\emptyset D, \emptyset W) + g(\emptyset B, \emptyset F)g(\emptyset D, \emptyset W)].$$

Let$\{e_1, e_2, e_3, ..., e_{n-1}, \xi\}$bealocalorthogonalbasisofthevectorfieldsinM^n.Usingthe factthat$\{\emptyset e_1, \emptyset e_2, \emptyset e_3, ..., \emptyset e_{n-1}, \xi\}$isalsolocalorthogonalbasis.Taking$B$=W=$e_i$in (8.5) and summing over i, weget

(8.6) $$\sum_{i=0}^{n-1}[g(R(\emptyset e_i \emptyset D)\emptyset F, \emptyset e_i) - 2g(\emptyset e_i, D)g(F, \emptyset e_i)] = \frac{1}{n-1}\sum_{i=0}^{n-1}[S(\emptyset D, \emptyset F)g(\emptyset e_i, \emptyset e_i)) - g(\emptyset D, \emptyset F)g(\emptyset e_i, \emptyset e_i) - S(\emptyset e_i, \emptyset F)g(\emptyset D, \emptyset e_i) + g(\emptyset e_i, \emptyset F)g(\emptyset D, \emptyset e_i)].$$

Also, it can be seen that[14]

(8.7) $$\sum_{i=0}^{n-1} g(R(\emptyset e_i \emptyset D)\emptyset F, \emptyset e_i) = S(\emptyset D, \emptyset F) + g(\emptyset D, \emptyset F),$$

(8.8)
$$\sum_{i=0}^{n-1} g(\emptyset e_i, \emptyset F) S(\emptyset D, \emptyset e_i) = S(\emptyset D, \emptyset F),$$

(8.9)
$$\sum_{i=0}^{n-1} g(\emptyset e_i, \emptyset e_i) = n-1,$$

and

(8.10) $$\sum_{i=0}^{n-1} g(\emptyset e_i, \emptyset F)\, g(\emptyset D, \emptyset e_i) = g(\emptyset D, \emptyset F).$$

Hence by virtue of equations (8.7), (8.8),(8.9) and (8.10) equation (8.6) becomes

(8.11) $$S(\emptyset D,\ \emptyset F) = 2(n-1)g(D,\ F) + (3-2n)g(\emptyset D,\ \emptyset F).$$

Now, using equations (2.2) and (2.10) in above equations, we get

(8.12) $$S(D, F) = g(D, F) + (3n-4)\eta(D)\eta(F).$$

Thus we can state the following theorem

Theorem 8.5. *An n-dimensional Ø-projectively flat K-Contact manifold admitting the quarter- symmetric metric connection is an η-Einstein manifold with respect to the Levi-Civita connection.*

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