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Special Finsler hypersurfaces admitting a parallel vector field

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Abstract. The study of special Finsler spaces has been introduced by M. Matsumoto. The purpose of the present paper is to study hypersurfaces of special Finsler spaces like quasi-C-reducible, C-reducible, Semi-C-reducible, P2-like, P-reducible, S3-like, C2-like and T-condition, which are admitting a parallel vector field $X^\alpha = X^i B_i^\alpha$ is defined on F^{n-1}.

1. Introduction

The study of spaces endowed with generalized metrics was initiated by P. Finsler in 1918. Since then many important result have been achived with respect to both the Differential geometry of Finsler space and its application to varitional problems, theoretical physics and Engineering. L. Berwald (1926) and E. Cartan (1951) made a great contribution in developing tensor calculus of Finsler spaces corresponding to that on Riemannian spaces.

The theory of subspaces (hypersurfaces) in general depends to a large extent on the study of the behavior of curves in them. The authors G. M. Brown (1968), MOOR (1972), C. Shibata (1980), M. Matsumoto (1985), B.Y. Chen (1973), C.S. Bagewadi (1982), L.M. Abatangelo, Dragomir and S. Hojo (1988) have studied different properties of subspaces of Finsler, Kahler and Riemannian spaces.

The author G.M. Brown [**1**] has published a paper - A study on tensors which characterize hypersurfaces of a Finsler space. M. Kitayama [**2**]- Finsler hypersurfaces and metric transformations. U.P. Singh - Hypersurfaces of C-reducible Finsler spaces, The author S.K. Narasimhamurthy and C.S. Bagewadi ([**6**],[**7**],[**8**],[**9**]) have studied and published the following research papers :- (1) C-conformal special Finsler spaces admitting a parallel vector field (2004) - Tensor (2) Infinitesimal C-conformal motions of special Finsler spaces (2003) - Tensor.

The terminology and notations are referred to [**1**], [**2**] and [**10**]. Let $F^n = (M^n, L)$ be a Finsler space on a differentiable manifold M endowed with a fundamental function

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$L(x, y)$. We use the following notations:[**10**]

$$
\begin{aligned}
&a) \quad g_{ij} = \frac{1}{2}\dot{\partial}_i\dot{\partial}_j L^2, \quad g^{ij} = (g_{ij})^{-1}, \quad \dot{\partial}_i = \frac{\partial}{\partial y^i},\\
&b) \quad C_{ijk} = \frac{1}{2}\dot{\partial}_k g_{ij}, \quad C^k_{ij} = \frac{1}{2}g^{km}(\dot{\partial}_m g_{ij}),\\
&c) \quad h_{ij} = g_{ij} - l_i l_j,\\
(1.1) \qquad &d) \quad \gamma^i_{jk} = \frac{1}{2}g^{ir}(\partial_j g_{rk} + \partial_k g_{rj} - \partial_r g_{jk}),\\
&e) \quad G^i = \frac{1}{2}\gamma^i_{jk} y^j y^k, \quad G^i_j = \dot{\partial}_j G^i, \quad G^i_{jk} = \dot{\partial}_k G^i_j, \quad G^i_{jkl} = \dot{\partial}_l G^i_{jk},\\
&f) \quad F^i_{jk} = \frac{1}{2}g^{ir}(\delta_j g_{rk} + \delta_k g_{rj} - \delta_r g_{jk}),\\
&g) \quad P_{hijk} = u_{(hi)}\{C_{ijk/h} + C_{hjr}C^r_{ik/0}\},\\
&h) \quad S_{hijk} = u_{(jk)}\{C_{hkr}C^r_{ij}\},
\end{aligned}
$$

where $\delta_j = \partial_j - G^r_j\dot{\partial}_r$, the index o means contraction by y^i and the notation $u_{(jk)}$ denotes the interchange on indices j and k and substraction.

2. Hypersurface F^{n-1} of the Finsler space F^n:

Finsler hypersurface $F^{n-1} = (M^{n-1}, L(u, v))$ of a Finsler space $F^n = (M^n, L(x, y))$ $(n \geqslant 4)$ may be parametrically represented by the equation

$$x^i = x^i(u^\alpha),$$

where Latin indices i, j, . . . etc are run from 1, . . . ,n and Greek indices α, β, . . . are run from 1, 2, . . . , n-1. The fundamental metric tensor $g_{\alpha\beta}$ and Cartan's C-tensor $C_{\alpha\beta\gamma}$ of F^{n-1} are given by [**2**], [**10**]:

$$
\begin{aligned}
(2.1) \qquad &a) \quad g_{\alpha\beta}(u, v) = g_{ij}(x, \dot{x})B^i_\alpha B^j_\beta,\\
&b) \quad C_{\alpha\beta\gamma} = C_{ijk}B^i_\alpha B^j_\beta B^k_\gamma,
\end{aligned}
$$

where $B^i_\alpha = \frac{\partial x^i}{\partial u^\alpha}$ is the matrix of projection factor, $\alpha = 1, ..., n-1$. The following notation are also employed.

$$B^i_{\alpha\beta} = \frac{\partial^2 x^i}{\partial u^\alpha \partial u^\beta}, \quad B^i_{o\beta} = v^\alpha B^i_{\alpha\beta}, \quad B^{ijk...}_{\alpha\beta\gamma....} = B^i_\alpha B^j_\beta B^k_\gamma.....$$

If the supporting element y^i at a point u^α of M^{n-1} is assumed to be tangential to M^{n-1}, we may then write $y^i = B^i_\alpha(u)v^\alpha$, where v^α is thought of as the supporting element of M^{n-1} at a point u^α.

We use the following notations of Finsler hypersurface [**9**], [**10**]:

$$
\text{(2.2)}\qquad
\begin{aligned}
&a)\quad g^{\alpha\beta} = g^{ij}B^{\alpha\beta}_{ij},\\
&b)\quad B^{\alpha}_{i} = g^{\alpha\beta}g_{ij}B^{j}_{\beta},\\
&c)\quad C_{\alpha} = B^{i}_{\alpha}C_{i},\quad C^{\alpha} = B^{\alpha}_{i}C^{i},\\
&d)\quad C^{\alpha}_{\beta\gamma} = B^{\alpha}_{i}C^{i}_{jk}B^{jk}_{\beta\gamma},\\
&e)\quad h_{\alpha\beta} = g_{\alpha\beta} - l_{\alpha}l_{\beta},\quad and,\quad h_{\alpha\beta} = h_{ij}B^{ij}_{\alpha\beta},\\
&f)\quad l_{\alpha} = B^{i}_{\alpha}l_{i}.
\end{aligned}
$$

3. Special Finsler hypersurfaces admitting a parallel vector field

Let F^n be an n-dimensional Finsler space with a fundamental function $L(x,y)$, where $y=\dot{x}$ and equipped with the Cartan connection $C\Gamma = (F^{i}_{jk}, N^{i}_{k}, C^{i}_{jk})$.
A vector field X^i in F^n, is called parallel if it satisfies the partial differential equations [**3**]:

$$\text{(3.1)}\qquad X^{i}_{/j} = \partial_j X^i - N^{h}_{j}\dot{\partial}_h X^i + X^h F^{i}_{hj} = \partial_j X^i + X^h F^{i}_{hj} = 0,$$

$$\text{(3.2)}\qquad X^{i}_{|j} = \dot{\partial}_j X^i + X^h C^{i}_{hj} = X^h C^{i}_{hj} = 0,$$

where ∂_j and $\dot{\partial}_j$ denote partial differentiations with respect to x^j and y^j respectively.

Let F^{n-1} be a hypersurface of Finsler space F^n and define a vector field $X^\alpha = X^i B^{\alpha}_{i}$ in F^{n-1}. Transvecting equations (3.1) and (3.2) by $B^{\alpha}_{i}B^{j}_{\beta}$, we obtain

$$\text{(3.3)}\qquad X^{\alpha}_{/\beta} = \partial_\beta X^\alpha - N^{\delta}_{\beta}\dot{\partial}_\delta X^\alpha + X^\delta F^{\alpha}_{\delta\beta} = \partial_\beta X^\alpha + X^\delta F^{\alpha}_{\delta\beta} = 0,$$

$$\text{(3.4)}\qquad X^{\alpha}_{|\beta} = \dot{\partial}_\beta X^\alpha + X^\delta C^{\alpha}_{\delta\beta} = X^\delta C^{\alpha}_{\delta\beta} = 0,$$

where ∂_β and $\dot{\partial}_\beta$ denote partial differentiations by x^β and y^β respectively. Thus we have the following

Lemma 3.1. *If F^{n-1} is a hypersurface of a Finsler space F^n, then the vector field $X^\alpha = X^i B^{\alpha}_{i}$ admits a parallel vector field to F^{n-1}, if the vector field X^i is parallel in F^n.*

The following expression is well known [**3**]

$$P_{hijk} = C_{ijk/h} + C_{hjr}C^{r}_{ik/0} - i/h.$$

i/h means the interchange of indices i and h in the forgoing tensors and substraction. Contracting above equation by $B^{hijk}_{\delta\alpha\beta\gamma}$, we get

$$\text{(3.5)}\qquad P_{\delta\alpha\beta\gamma} = C_{\alpha\beta\gamma/\delta} + C_{\delta\beta\rho}C^{\rho}_{\alpha\gamma/0} - \alpha/\delta.$$

Since the relation (2.1)(b) yields

$$\text{(3.6)}\qquad C_{\alpha\beta\gamma/\delta} = C_{ijk/\delta}B^{ijk}_{\alpha\beta\gamma} + C_{ijk}B^{ik}_{\alpha\gamma}Z^{j}_{\beta\delta} + C_{ijk}B^{ij}_{\alpha\beta}Z^{k}_{\gamma\delta}$$

where $Z^{i}_{\alpha\delta} = B^{i}_{\alpha/\delta}$ and $C_{ijk/h}B^{h}_{\delta}$.

Contracting (3.5) by X^α and using (3.4), then by simple calculation, we get

$$X^\alpha P_{\delta\alpha\beta\gamma} = 0, \tag{3.7}$$

where $P_{\delta\alpha\beta\gamma}$ is the component of induced curvature tensor with respect to the induced Cartan connection $C\Gamma = (F^\alpha_{\beta\gamma}, N^\alpha_\gamma, C^\alpha_{\beta\gamma})$.
Next we know the following [**3**]

$$S_{hijk} = C_{hkr}C^r_{ij} - k/j.$$

Contracting above by $B^{hijk}_{\delta\alpha\beta\gamma}$, we get

$$S_{\delta\alpha\beta\gamma} = C_{\delta\gamma\rho}C^\rho_{\alpha\beta} - \gamma/\beta.$$

Contracting above by X^δ and using (3.3) and (3.4), we get

$$X^\delta S_{\delta\alpha\beta\gamma} = 0, \tag{3.8}$$

LEMMA 3.2. *From the Ricci identities , the fallowing integrability conditions hold for a Finsler hypersurfaces*

$$\begin{aligned} &a) \quad X^\delta P_{\delta\alpha\beta\gamma} = 0,\\ &b) \quad X^\delta S_{\delta\alpha\beta\gamma} = 0,\\ &c) \quad X^\delta R_{\delta\alpha\beta\gamma} = 0, \end{aligned}$$

where $P_{\delta\alpha\beta\gamma}, S_{\delta\alpha\beta\gamma}, R_{\delta\alpha\beta\gamma}$ are the components of the curvature tensor with respect to $C\Gamma$.

Now we shall consider the special Finsler hypersurfaces like quasi-C-reducible, semi-C-reducible, C-reducible, C2-like, P2-like Finsler spaces, S3-like, C^h-recurrent and T-Conditions which admits the parallel vector fields.

DEFINITION 3.1. A Finsler space $F^n (n > 2)$ is called a quaci-C-reducible, if the torsion tensor satisfies the equation

$$C_{ijk} = A_{ij}C_k + A_{jk}C_i + A_{ki}C_j, \tag{3.9}$$

where A_{ij} is a symmetric Finsler tensor field and satisfies $A_{i0} = A_{ij}y^j = 0$.

Contracting (3.9) by projection factor $B^{ijk}_{\alpha\beta\gamma}$, we obtain

$$C_{ijk}B^{ijk}_{\alpha\beta\gamma} = (A_{ij}C_k + A_{jk}C_i + A_{ki}C_j)B^{ijk}_{\alpha\beta\gamma}.$$

Using (2.1)(b) and (2.2)(c), we obtain

$$C_{\alpha\beta\gamma} = A_{\alpha\beta}C_\gamma + A_{\beta\gamma}C_\alpha + A_{\gamma\alpha}C_\beta, \tag{3.10}$$

where we have set $A_{\alpha\beta} = A_{ij}B^{ij}_{\alpha\beta}$ and is a symmetric Finsler tensor field on Finlser hypersurface F^{n-1}.
Contracting (3.10) by $X^\alpha X^\beta$ and using (3.4), we obtain

$$X^\alpha X^\beta A_{\alpha\beta}C_\gamma = 0. \tag{3.11}$$

This implies $C_\gamma = 0$, if $\lambda(= X^\alpha X^\beta A_{\alpha\beta}) \neq 0$. According to Deicke's theorem we state:

THEOREM 3.1. *If quaci-C-reducible Finsler hypersurface admits a parallel vector field, then it is Riemannian provided* $\lambda(= X^\alpha X^\beta A_{\alpha\beta}) \neq 0$.

DEFINITION 3.2. A Finsler space $F^n(n > 2)$ is said to be C-reducible, if it satisfies the equation

$$(n+1)C_{ijk} = h_{ij}C_k + h_{jk}C_i + h_{ki}C_j, \tag{3.12}$$

where $C_i = g^{jk}C_{ijk}$.

Contracting (3.12) by $B^{ijk}_{\alpha\beta\gamma}$ and using (2.1)(b) and (2.2)(c)(e), we obtain

$$nC_{\alpha\beta\gamma} = h_{\alpha\beta}C_\gamma + h_{\beta\gamma}C_\alpha + h_{\gamma\alpha}C_\beta, \tag{3.13}$$

where $C_\alpha = C_i B^i_\alpha = g^{\beta\gamma}C_{\alpha\beta\gamma}$. Contracting (3.13) by $X^\alpha X^\beta$ and using (3.4), we obtain $X^\alpha X^\beta h_{\alpha\beta}C_\gamma = 0$. Thus we state:

THEOREM 3.2. *A C-reducible Finsler hypersurface admitting parallel vector field, is Riemannian , provided* $\mu(= X^\alpha X^\beta h_{\alpha\beta}) \neq 0$.

DEFINITION 3.3. A Finsler space $F^n(n > 2)$ with non-zero length C of the torsion vector C_i is said to be semi-C-reducible, if the torsion tensor C_{ijk} is of the form

$$C_{ijk} = P(h_{ij}C_k + h_{jk}C_i + h_{ki}C_j)/(n+1) + qC_iC_jC_k/C^2, \tag{3.14}$$

where $C_2 = g^{ij}C_iC_j = C_iC^i$ and $p + q = 1$.

Contracting (3.14) by $B^{ijk}_{\alpha\beta\gamma}$ and using (2.1)(b) and (2.2)(c)(e), we obtain

$$C_{\alpha\beta\gamma} = P(h_{\alpha\beta}C_\gamma + h_{\beta\gamma}C_\alpha + h_{\gamma\alpha}C_\beta)/n + qC_\alpha C_\beta C_\gamma/\overline{C}^2, \tag{3.15}$$

where $\overline{C}^2 = C_\alpha C^\alpha$, $C_\alpha = C_i B^i_\alpha$ and $C^\alpha = C^i B^\alpha_i$.

Contracting (3.15) by $X^\alpha X^\beta$ and using (3.4), we obtain

$$X^\alpha X^\beta p h_{\alpha\beta}C_\gamma = 0.$$

Thus we state:

THEOREM 3.3. *A semi-C-reducible Finsler hypersurface* F^{n-1} *admitting parallel vector field, is Riemannian provided* $p\mu \neq 0$.

DEFINITION 3.4. A Finsler space $F^n(n > 2)$ with $C^2 = C_iC^i \neq 0$ is called C2-like, if the torsion tensor C_{ijk} satisfies the equation

$$C_{ijk} = C_iC_jC_k/C^2.$$

Contracting above by $B^{ijk}_{\alpha\beta\gamma}$ and using (2.1)(b) and (2.2)(c)(e), we obtain

$$C_{\alpha\beta\gamma} = C_\alpha C_\beta C_\gamma/\overline{C}^2, \tag{3.16}$$

where $\overline{C}^2 = C_\alpha C^\alpha \neq 0$. Now we consider the special case for $p = 0$ in equation (3.15) and by virtue of $p+q = 1$, we have $q = 1$ and thus we are led to the following theorem:

THEOREM 3.4. *A semi-C-reducible Finsler hypersurface* F^{n-1} *admitting a parallel vector field is a C2-like Finsler hypersurface.*

DEFINITION 3.5. A Finsler space $F^n(n > 2)$ is P2-like, if it is characterized by

$$P_{hijk} = K_h C_{ijk} - K_i C_{hjk}, \tag{3.17}$$

where $K_h = K_h(x, y)$ is a covariant vector field.

Contracting (3.17) by $B^{hijk}_{\delta\alpha\beta\gamma}$ and using (2.1)(b), we get

$$P_{\delta\alpha\beta\gamma} = K_\delta C_{\alpha\beta\gamma} - K_\alpha C_{\delta\beta\gamma}, \tag{3.18}$$

where we set $K_\alpha = K_i B^i_\alpha$ is a covariant vector field on F^{n-1}.
Contracting (3.18) by X^δ and using (3.4) and (3.7), we get $X^\delta K_\delta C_{\alpha\beta\gamma} = 0$. Thus we state:

THEOREM 3.5. *A P2-like Finsler hypersurface F^{n-1} admitting parallel vector field, is Riemannian provided $X^\delta K_\delta \neq 0$.*

DEFINITION 3.6. A Finsler space F^n is called S3-like, if the curvature tensor S_{hijk} satisfies the equation

$$L^2 S_{hijk} = S(h_{hj}h_{ik} - h_{hk}h_{ij}), \tag{3.19}$$

where the scalar curvature $S = S_{hijk}g^{hj}g^{ik}$ is a function of position alone.

Contracting (3.19) by $B^{hijk}_{\delta\alpha\beta\gamma}$ and using (2.2)(e), we get

$$L^2 S_{\delta\alpha\beta\gamma} = S(h_{\delta\beta}h_{\alpha\gamma} - h_{\delta\gamma}h_{\alpha\beta}), \tag{3.20}$$

where the scalar curvature $S = S_{\delta\alpha\beta\gamma}g^{\delta\beta}g^{\alpha\gamma}$, again Contracting (3.20) by $X^\delta g^{\alpha\gamma}$ and using (3.8), we get $S = 0$.
Thus we state:

THEOREM 3.6. *If a S3-like Finsler hypersurface F^{n-1} admitting parallel vector field, then the curvature tensor $S_{\delta\alpha\beta\gamma}$ vanish.*

DEFINITION 3.7. A Finsler space $F^n(n > 2)$ will be called called $C^h - recurrent$, if the torsion tensor C_{ijk} satisfies the equation

$$C_{ijk/l} = K_l C_{ijk}, \tag{3.21}$$

where $K_l = K_l(x, y)$ is a covariant vector field.

Contracting (3.21) by $B^{hijk}_{\delta\alpha\beta\gamma}$ and using (2.1(b)),(3.6) we get

$$C_{\alpha\beta\gamma/\rho} = K_\rho C_{\alpha\beta\gamma}, \tag{3.22}$$

where we set $K_\rho = K_i B^i_\rho$ is a covariant vector field on F^{n-1}.
Contracting (3.5) by X^δ and using (3.3), (3.4) and (3.7), we have

LEMMA 3.3. *For a torsion tensor $C_{\alpha\beta\gamma}$ and a parallel vector field X^δ, we have*

$$X^\delta C_{\alpha\beta\gamma/\delta} = 0. \tag{3.23}$$

Contracting (3.22) by X^ρ and using lemma(3.3) , we obtain $X^\rho K_\rho C_{\alpha\beta\gamma} = 0$. Thus we state:

THEOREM 3.7. *A C^h-recurrent Finsler hypersurface F^{n-1} admitting a parallel vector field, is Riemannian provided $X^\rho K_\rho \neq 0$.*

Now we shall consider the T-condition [**11**]:

$$T_{hijk} = LC_{hij/k} + l_h C_{ijk} + l_i C_{hjk} + l_j C_{hik} + l_k C_{hij} = 0,$$

where the T-tensor is completly symmetric. Contracting above equation by $B^{hijk}_{\delta\alpha\beta\gamma}$ and using (3.6), we obtain

$$T_{hijk}B^{hijk}_{\delta\alpha\beta\gamma} = LC_{hij/k} + l_h C_{ijk} + l_i C_{hjk} + l_j C_{hik} + l_k C_{hij} B^{hijk}_{\delta\alpha\beta\gamma} = 0,$$

$$T_{\delta\alpha\beta\gamma} = LC_{hij/k}B^{hijk}_{\delta\alpha\beta\gamma} + l_h B^h_\delta C_{ijk} B^{ijk}_{\alpha\beta\gamma} + l_i B^i_\alpha C_{hjk} B^{hjk}_{\delta\beta\gamma} + l_j B^j_\beta C_{hik} B^{hik}_{\delta\alpha\gamma} + l_k B^k_\gamma C_{hij} B^{hij}_{\delta\alpha\beta} = 0,$$

$$T_{\delta\alpha\beta\gamma} = LC_{\delta\alpha\beta/\gamma} + l_\delta C_{\alpha\beta\gamma} + l_\alpha C_{\delta\beta\gamma} + l_\beta C_{\delta\alpha\gamma} + l_\gamma C_{\delta\alpha\beta} = 0.$$

Contracting above equation by X^δ and using (3.4), we get

$$X^\delta T_{\delta\alpha\beta\gamma} = LX^\delta C_{\delta\alpha\beta/\gamma} + l_\delta X^\delta C_{\alpha\beta\gamma} + l_\alpha X^\delta C_{\delta\beta\gamma} + l_\beta X^\delta C_{\delta\alpha\gamma} + l_\gamma X^\delta C_{\delta\alpha\beta} = 0,$$

that implies, $l_\delta X^\delta C_{\alpha\beta\gamma} = 0$. Thus we state:

THEOREM 3.8. *If F^{n-1} is satisfying T-condition admits a parallel vector field X^α, then the Finsler hypersurface F^{n-1} is Riemannian provided $l_\delta X^\delta \neq 0$.*

Finally the generalized T-condition is defined by

$$T_{ij} = T_{ijhk} g^{hk} = LC_{i/j} + l_i C_j + l_j C_i = 0.$$

Contracting above equation by $B^{ij}_{\alpha\beta}$, we obtain

$$T_{\alpha\beta} = LC_{\alpha/\beta} + l_\alpha C_\beta + l_\beta C_\alpha = 0.$$

Contracting above equation by X^α, we get

$$X^\alpha T_{\alpha\beta} = X^\alpha LC_{\alpha/\beta} + X^\alpha l_\alpha C_\beta + X^\alpha l_\beta C_\alpha = 0. \tag{3.24}$$

Using equation (3.4) we get $X^\alpha l_\alpha C_\beta = 0$. According to Deckies theorem we state:

THEOREM 3.9. *If a Finsler space F^n satisfying above equation (3.24) admits a parallel vector field X^α, then F^{n-1} is Riemannian provided $l_\alpha X^\alpha \neq 0$.*

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